

International Geology Review

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INTERNATIONAL GEOLOGY REVIEW

IGR transliteration of Russian

The AGI Translation Office has adopted the essential features of Cyrillic transliteration recommended by the U. S. Department of the Interior, Board on Geographic Names, Washington D. C.

However, the AGI Translation Office recommends the following modifications:

1. Ye initially, after vowels, and after Ъ, Ь Customary usage calls for "ie" in many names, e. g., SOVIET KIEV, DNIEPER, etc.; or "ye", e. g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".
2. Omitted if preceding a "y", for example, Arkhangelsky (not "iy"; not "ii").
3. Generally omitted.

NOTE: Well-known place and personal names that have wide acceptance will be used. Some translations may include elements of previous German transliteration from the Russian; this occurs in IGR most commonly in maps and lists of references. The reader's attention is called to the following variations between German and English systems which may cause confusion when trying to check back to original Russian sources.

| Alphabet | transliteration | |
|----------|-----------------|----------------------|
| А | а | a |
| Б | б | b |
| В | в | v |
| Г | г | g |
| Д | д | d |
| Е | е | e, ye ⁽¹⁾ |
| Ё | ё | ë, yë |
| Ж | ж | zh |
| З | з | z |
| И | и | i ⁽²⁾ |
| Й | й | y |
| К | к | k |
| Л | л | l |
| М | м | m |
| Н | н | n |
| О | о | o |
| П | п | p |
| Р | р | r |
| С | с | s |
| Т | т | t |
| У | у | u |
| Ф | ф | f |
| Х | х | kh |
| Ц | ц | ts |
| Ч | ч | ch |
| Ш | ш | sh |
| Щ | щ | shch |
| Ъ | ъ | " ⁽³⁾ |
| Ы | ы | y |
| Ь | ь | " ⁽³⁾ |
| Э | э | e |
| Ю | ю | yu |
| Я | я | ya |

| German | English |
|---------|---------|
| w | v |
| s | z |
| ch | kh |
| tz | ts |
| tsch | ch |
| sch | sh |
| schtsch | shch |
| ja | ya |
| ju | yu |

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GEOLOGICAL BASES FOR THE EXPLORATION AND PROSPECTING OF ORE DEPOSITS, (PART II, SECTIONS III AND IV) ¹

by

V. I. Smirnov

• translated by M. Irving Smith •

EDITOR'S NOTE

This article is a translation of two sections of the above-mentioned book by V. I. Smirnov. It was translated under NSF Grant No. 10,050 to the Geochemical Society and the generous aid of the Foundation in helping make this information available in English is hereby gratefully acknowledged.

The other sections of the book are, for the most part, descriptions of well-known types of ore deposits with a high proportion of the examples taken from American and other western deposits. Therefore, these sections are not being translated at this time. --E. Ingerson.

ABSTRACT

The Russian system of classification of ore reserves is defined; it includes five categories of reserves. Methods of estimating and designating the four main groups of ore deposits for the purpose of estimating reserves are described. Examples used include sedimentary marine iron, manganese, and bauxite deposits; residual limonitic iron ore, alluvial bauxite, magnetite skarn, copper-bearing sandstones, stratified copper-nickel sulfides, vein disseminated copper in secondary quartzite, lensing pyrite, hydrothermal ore vein, chromite, scheelite skarn, lateritic nickel ores, and placers. --M. Russell.

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Translated from *Geologicheskie osnovy poiskov i razvedok rudnykh mestorozhdenii*, Sections 3 and 4 of Part 2, pp. 346-380, Izdatel'stvo Moskovskogo Universiteta, 1957.

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SECTION III. GENERAL BASES FOR THE CLASSIFICATION OF RESERVES.

The quantity of ore and metal, called reserves, existing in a prospected deposit, is estimated from the results of prospecting. Detailed information concerning the classification of reserves and methods for estimating them is presented in Part IV of this book. In this chapter we present only general information on the classification of reserves, essential to the understanding of prospecting methods for different types of ore deposits.

Ore and metal reserves within a prospected deposit are estimated by determining the dimensions of ore bodies and the content of metal according to particular intersections in test shafts or borings, by interpolating these data to the space between the intersections, and also by extrapolating them beyond the limits of the intersections.

Due to the fact that the regularity of change in the above indicated magnitudes between the intersections and beyond their limits is usually unknown, both interpolation and extrapolation are carried out using the rectilinear method, i.e., the boundaries of the measured magnitudes are joined by straight lines.

Such rectilinear outlining, as a rule, does not coincide with the true boundaries of change in the measured magnitudes. The outlines may be more or less than these magnitudes as Figure 182.²

For this reason, the reserves of mineral raw material, as estimated by allowing the above-indicated rectilinear measurements, can always differ from the actual reserves.

The amount of deviation of the estimated reserves from the actual reserves depends chiefly on two factors: On the one hand, it de-

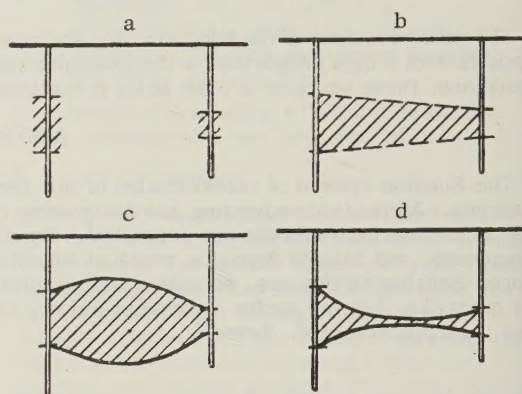


FIGURE 182. Determination of the area of an ore body between two borings (in cross section): a) two borings intersecting an ore body of varying thickness; b) area of an ore body bounded by the method of straight-line interpolation; c) area of an ore body with swelling between the borings; in this case, it is larger than the area as determined by the straight-line method of interpolation; d) area of an ore body with pinching-out between the borings; in this case it is less than the area as determined by the straight-line method of interpolation.

pends upon the complexity of the structure of the ore bodies and the distribution of metal in them, and on the other, upon the amount of prospecting detail. Obviously, the more complex a deposit and the sharper the variations in the thickness of ore bodies and in their metal content, the greater will be the deviation of these magnitudes from the average data obtained from adjacent intersections, and the less can be the reliability of the estimated reserves. It is also obvious that the greater the distance between the intersections and the less their number, the greater may be the error introduced into the determination of average magnitudes between them, and the less reliable will be the estimated reserves. In view of what has been said above, the following rule may be formulated: The more irregular ore bodies are in their morphology and metal distribution and the less detail there is in exploration, the less reliable are the figures on estimated reserves.

Reserves are divided into a series of cate-

² The numbering of figures and tables is the same in this translation as they appear in the original Russian book.

gories according to the degree of reliability of the magnitudes of estimated reserves and the amount of prospecting and investigation. Such a division based on the degree of reliability of prospecting and the amount of investigation is called classification of reserves.

In our country, where deposits of useful minerals are a most important part of the natural productive strength of the Soviet socialist state, exceptional importance is attached to a single method of estimating reserves. For this reason, a statute governing the classification of reserves of deposits of useful solid ores was confirmed by the Soviet government and is a document having the force of law. According to this statute, reserves are divided into five categories designated by the letters, A₁, A₂, B, C₁ and C₂. Categories A and B are usually called high and categories C₁ and C₂, low. In accordance with the above, there may be different categories of reserves in various deposits possessing differing complexity of structure and ore composition and having identical density of prospecting pattern and identical number of prospecting intersections, just as in the same deposit, reserves of different categories are estimated for the various parts of it prospected in different degrees of detail.

Reserves are referred to one or the other category on the basis of a series of features, among which three are decisive: 1) reliability of the quantity of estimated reserves, 2) fullness of the investigation of the grade and technological treatment of useful ore, and 3) extent to which the natural factors determining the conditions for conducting mining operations have been investigated--primarily the extent to which the hydrogeology of a deposit has been studied. Each category of reserves is determined by a set of predetermined features; failure to conform to one of them prevents placing the reserves in a category which satisfies the remaining features.

The classification of reserves of useful ores in effect in our country, instituted for the purpose of assuring the planned development of the peoples' socialist economy, makes it possible to determine the readiness of reserves on which to base plans and make capital investments in setting up mining enterprises. This readiness is determined by the relationship of the quantity of reserves of categories A₂, B and C₁. This relationship is established on the basis of the following features.

The development of projects and apportionment of capital investments for setting up of mining enterprises is decided on the basis of the reserves of categories A₂+B+C₁, but in deposits the prospecting of which, according to category A₂, is inexpedient, due to small dimensions, complexity of structure or distribution of valuable components, it is decided on

the basis of reserves of categories B+C₁. For particular ore deposits having an especially complex structure or distribution of valuable components, which cannot be determined even with a close pattern of borings and shafts, the development of projects and the apportionment of capital investment for the building of mining enterprises may be allowed on the basis of reserves of category C₁ if the conditions for developing the deposit and the nature and technology of the treatment of useful ores is fully enough determined.

In planning mining enterprises, reserves of category C₂ are taken into account along with those of other categories in order to determine the possibilities future development.

Following is a complete official description of reserve categories:

Category A₁: reserves fully studied and outlined by preparatory shafts or borings of operational prospecting; hydrogeological conditions of mining have been studied; economic grades of useful minerals and their distribution have been established in each block; the nature and technology of treating useful minerals have been studied on the basis of experience in industrial utilization.

Category A₂: reserves have been prospected in detail and outlined by shafts or borings; conditions of deposition, interrelationships of natural types, and economic grades of useful mineral, as well as the hydrogeological conditions of the deposit and the conditions of its development, have been studied; the grade and technological nature of the useful mineral have been determined to a degree of detail which makes possible the planning of the treatment and technology for utilizing the useful mineral.

Category B: reserves have been prospected and outlined by shafts or borings; conditions of deposition have been studied; natural types and economic grades of useful mineral have been established without detailing their distribution; the grade and technological properties of the useful mineral have been studied to a degree which makes possible a choice of scheme for its treatment; general conditions of development, as well as the general hydrogeological conditions of the deposit, have been rather fully determined.

Category C₁: reserves have been determined on the basis of a sparse pattern of borings or shafts; reserves adjoining the limits of reserves of categories A₁, A₂ and B; reserves of particularly complex deposits, for which, in spite of a close pattern of exploratory shafts, the distribution of the valuable component or mineral has not been determined; the quality, natural type, economic grade and technological treatment of the useful mineral have been tentatively

determined on the basis of analyses or laboratory tests of samples taken, and also by analogy with deposits already studied; general conditions of development, as well as the general hydrogeological conditions of the deposit, have been tentatively studied.

Category C₂: reserves of adjoining segments of deposits prospected according to categories A₂, B and C₁, and also reserves assumed to exist on the basis of geological and geophysical data confirmed by testing the useful mineral in particular borings and shafts.

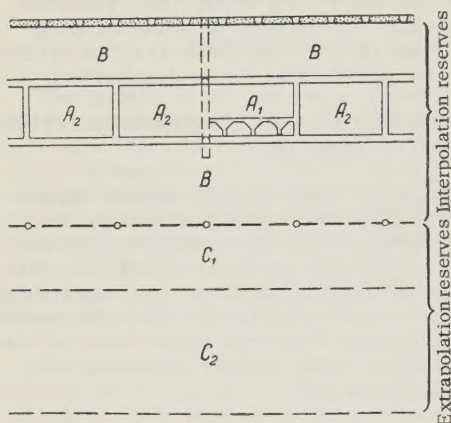


FIGURE 183. Classification of the reserves of a part of an ore vein. Projection in the plane of the vein:

— shafts - - - borings

In Figure 183 we indicate, by way of a practical example of the classification of reserves, the distribution of reserves by categories for an ore vein which has been prospected by shafts and borings.

SECTION IV. PROSPECTING OF DIFFERENT TYPES OF ORE DEPOSITS.

Chapter 1. Grouping of major deposits for uniform methods of prospecting.

The great diversity of ore deposits may be reduced to a few groups, for which the prospecting of reserves of the same type require closely similar methods of prospecting. The following basic features serve for such a grouping: size of ore bodies, nature of the continuity of mineralization, degree of morphological regularity in the ore bodies, and the distribution of metal in them.

Size of ore bodies.

In size, ore bodies may be divided into three groups: 1) large, 2) medium, and 3) small.

Large bodies are beds, blocks and other forms of deposits extending for many hundreds of meters or for kilometers. Medium bodies include blocks, lenses, veins, and other deposits traced for hundreds of meters; they are often small in thickness. Small bodies are represented by schlieren, druses, pipes and small veins having a dimension in the direction of greatest extent in units or tens of meters.

Morphological stability of ore bodies.

According to degree of morphological stability, three groups of deposits may be distinguished: 1) stable, 2) variable and 3) extremely variable.

Beds and bed-like deposits with very gradual and insignificant changes in thickness over a great distance are most frequently morphologically stable bodies. Morphologically variable are beds, veins, lenses, and other bodies possessing infrequent alteration of pinch and swell in the ore bodies. Morphologically extremely variable deposits of varying form are characterized by sporadic, sharp, thick swells separated by thin portions of ore bodies; this group contains also thin ore bodies broken up by frequent faults of considerable displacement (more than 3-5 meters).

Continuity of mineralization.

In respect to the degree of continuity of mineralization,³ it is possible to distinguish four groups of deposits having different ore-bearing coefficients: 1) continuous, 2) slightly interrupted, 3) interrupted and 4) extremely interrupted.

An ore-bearing coefficient may serve for orienting the degree of continuity of mineralization. We usually have in mind the area coefficient of ore content, representing, as has been already pointed out, the ratio of the area occupied by the ore segments to the entire area of the ore-bearing zone.

Continuous bodies contain economic mineralization over their entire extent and have an ore-bearing coefficient of one.

Bodies with slightly interrupted mineralization possess unimportant interruptions in the form of "windows" in the general body of economic ores. In this case, the areas made up of economic ore predominate in the area of the ore body, and the ore-bearing coefficient fluctuates between 0.7 and 1.

³ This feature, used for grouping one of the types of deposits, was first indicated by D. Ya. Surazhskim.

In interrupted bodies the ratio between the area occupied by economic ore and that occupied by the uneconomic portions is approximately the same, and the ore-bearing coefficient changes from 0.4 to 0.7.

Extremely interrupted bodies are characterized by sporadic portions of economic ores separated by large barren areas. Here, in the plane of the ore-bearing zone the barren areas predominate and the ore-bearing coefficient has a magnitude of less than 0.4.

Using the concept of the interrupted nature of ore bodies, one must take into account not only the degree of interruption, but also its nature as determined by the dimensions of the portions of conditional ore and by the regularity of their distribution in the general ore-bearing body. These portions should not be too large where they are to be prospected as independent bodies, nor too small where they are to be developed selectively in exploitation. In these cases, the concept of the interrupted nature of ore bodies becomes meaningless. Moreover, we bear in mind the unconcentrated and more or less irregular distribution of the ore portions within the limits of the ore-bearing area, where the ore-bearing coefficient may be revealed basically by statistical methods.

Regularity of metal distribution in ore bodies.

It is possible to distinguish four groups of deposits according to the degree of regularity of metal distribution in ore bodies: 1) very regular and regular, 2) irregular, 3) very irregular, and 4) extremely irregular.

The coefficient of metal-content variation in the ore body may serve as an orienting characteristic for these groups. In ore bodies having very regular and regular metal distribution, the content of metal changes only slightly and gradually in the large areas. The variation coefficient rarely reaches 40 percent, and it is usually lower. Typical representatives of this group are the sedimentary marine deposits, lake-swamp deposits, and ancient river deposits, of ferrous⁴ metals and bauxites.

Bodies having irregular metal distribution possess substantial fluctuations in metal content at considerable intervals. The variation coefficient lies within the limits of 40 to 100 percent. Usually included in this group is a broad series of endogenic non-ferrous metals.

Ore deposits having very irregular metal

⁴In the author's classification, ferrous ("black") metals include iron, manganese, chromium and titanium; non-ferrous ("colored") include copper, lead, zinc, nickel and antimony.

distribution are characterized by sharp local deviations in metal content from the average level. The variation coefficient fluctuates between 100 and 150 percent. To this type belong principally deposits of rare metals and gold.

Finally, deposits having extremely irregular metal distribution in ore bodies are characterized by small and rare portions of exceptionally rich ores in the general mass of ore, in which the metal content exceeds the average by hundreds and even thousands of times. The variation coefficient of metal content for these deposits exceeds 150 percent. Included among these are some deposits of rare metals, principally gold, with exceptionally uneven distribution of druses of super-rich ore in the ore bodies.

In speaking of uneven metal distribution in ore, one must take into account not only the degree of unevenness, but also the nature of the variability of ore bodies. D. A. Zenkov (1955) distinguishes four types of variability: 1) gradual, continuous and regular; 2) gradual, continuous but irregular; 3) interrupted, spotty but regular, and 4) interrupted, spotty and irregular. The morphology of ore bodies (thickness and cross section) change according to the first two types of variability, and the metal content of ore, according to the second two.

Groups of ore deposits.

Proceeding from the above-enumerated features, four groups of deposits may be distinguished, within the limits of which it is necessary, for prospecting reserves of one and the same category, to distribute shafts or borings at definite distances suitable for a given group. These methods of prospecting, as well as the distances between shafts and borings for particular groups of ore deposits in general and for specific representatives of them in particular, must not be regarded as hard and fast indications, but merely as average experimental data. Justified deviation from them which will improve the quality of prospecting, shorten its time, and decrease its cost can only be encouraged.

The four groups of deposits distinguished are close to the grouping of ore deposits established by the GKZ in 1953 for determining the relationships of ore reserves of various categories essential for the planning and construction of mining enterprises. Note: This grouping of the VKZ (All-Union Commission on Mineral Reserves--now GKZ) was confirmed after the final draft of the manuscript of the present book for the first edition. It is kept in the second edition also, since experience has shown that it is possible to use it without destroying the principles of grouping of the VKZ (GKZ). Moreover, the four groups of deposits described here approximate the four groups of non-ferrous and rare metals of GKZ, and the first

two groups nearly correspond to the first and second groups of deposits of bauxites and manganese of GKZ and to the first, second and third groups of iron deposits. They differ from our grouping of 1950, in which five groups were established, in that in theirs, the last two groups, being close, were combined into one-fourth.

There was also some redistribution of deposits among groups, conforming to a more exact affiliation with a particular subdivision. Besides, in establishing the groups of deposits, there was borne in mind not only the dimensions of a deposit and the nature of regularity of form, together with the distribution of metal in the ore body, as was done in the grouping of the GKZ, but also the geological conditions of the formation of ore bodies which determine the peculiarities of their structure as well as the degree of regularity of mineralization. These last characteristics, which constitute, with others, the features determining the division of deposits into groups according to prospecting conditions, improve the indicated grouping by basing it not only on formal parameters, but also on genetic types of ore formation.

Below is given a brief characterization of the four groups of deposits designated for providing a choice of methods of prospecting, and following this are presented examples of the prospecting of deposits according to these groups.

First group: To this group belong extended bedded deposits, whose most typical representatives are sedimentary marine deposits. They have large dimensions, continuous ore content, sustained form, and even metal distribution. Included among them are sedimentary iron deposits of the Kerchensk Basin type, and sedimentary manganese deposits of the Chiatur and Nikopol' type; to the same group belong also the metamorphic deposits of ferrous quartzites of the Krivoi Rog and Kursk magnetic anomaly type and similar ones. Close to this group are also the Devonian sedimentary marine deposits of Ural bauxites, which, however have a more complex morphology of ore beds, making them close to the deposits of the second group.

This group is the simplest in respect to prospecting conditions. Reserves of category A₂ in deposits of this group can be determined by drilling with distances between borings of 100-150 m (with partial control by shallow shafts). Reserves of category B, especially, can be determined by drilling with distances between borings of 200-300 m. Reserves of categories C₁ and C₂ are determined by extrapolation beyond the limits of the area of reserves of higher categories. Thus, in prospecting deposits of the first group, drilling systems of prospecting are widely used. In normally prospected deposits of this group,

reserves of categories A₂ + B predominate.

Second group: This group embraces a considerably greater variety of ore deposits of different genesis. They have large dimensions, uninterrupted, or slightly interrupted, ore content, and usually relatively uneven metal distribution in ore bodies. The following, in particular, belong to it:

a) lens-like deposits of platform sedimentary deposits of iron, manganese and bauxites;

b) sheet deposits of iron and manganese ores, large deposits of silicate nickel ores and also bauxites of surface-weathering;

c) bottom deposits, large blocks and fields of disseminated ores of chromite, ilmenite-magnetite, and copper-nickel magmatic deposits;

d) large deposits of iron ore in skarns;

e) large lens-like, veined and block-like deposits of dense pyritic and disseminated polymetallic and copper ores of hydrothermal deposits;

f) thin-stockwork hydrothermal deposits of interveined-disseminated copper ores of secondary quartzites;

g) bedded deposits of disseminated copper and polymetallic ores in thick layers of sedimentary rocks;

h) veined and pipe-like bodies of concentrated iron ores lying between ferrous quartzites.

Deposits of this group are by far the more complex objects for prospecting. Reserves of category A₂ in them may be shown by borings at close intervals, as little as 25-50 m, with a considerable total number of them (generally not less than 20) and requiring control of drilling results by shafts. Reserves of category B in these deposits are easily shown by drilling with distances between borings of 50-100 m. Reserves of category C₁ may be supported by isolated borings beyond the limits of the areas with reserves of high categories, and also by the method of extrapolation. Reserves of category C₂ are determined by extrapolation.

In prospecting reserves in category B in deposits of the second group, drilling systems are widely used. To prospect reserves of category A₂ it is also possible to employ mining drilling systems. In normally prospected deposits of the second group, reserves of category B predominate.

Third group: Into this group go average-sized, predominantly endogenic deposits, principally

of non-ferrous, rare, radioactive and noble metals of varying form of slightly interrupted or interrupted mineralization, and with irregular and also very irregular metal distribution in ore bodies. In it, specifically, are included the following:

- a) veins of copper, polymetallic, some gold, cobalt-nickel, uranium, tin, antimony, arsenic, and other hydrothermal deposits and also average-sized stockworks, blocks and lenses.
- b) the majority of the deposits of non-ferrous and rare metals in skarns;
- c) veins and blocks of chromitic, ilmenite-magnetite, and copper-nickel magmatic deposits;
- d) deposits of lateritic silicate nickel ores.

Prospecting of deposits of the third group is a still more complicated matter. Reserves of category A₂ can be prospected in the majority of cases only by the help of shafts, by cutting up normal exploitative blocks, with a total number of not less than 5-7. Only in particular cases, as, for example, in prospecting shallow deposits of lateritic silicate nickel ores, is prospecting done by drilling, using a pattern as close as 20 x 10 to 10 x 10 m. Included in category B are those parts of ore bodies which are prospected by shafts with distances between them exceeding the dimensions of normal operational blocks along both dip and strike, but not more than double. Included among reserves of this category are also those parts of ore bodies adjacent to an area with reserves of category A₂ not more than 100-150 m away. These are prospected by borings with distances between them of not more than 40-70 m. Reserves of category C₁ may be determined by drilling data with distances between borings up to 90-150 m, and also by extrapolation from the limits of an area with reserves of high categories, for 1 to 2 stages. Reserves of category C₂ are determined by isolated borings and extrapolation.

In deposits of the third group, mining and mine drilling systems of prospecting are most prevalent. Reserves of categories B + C₁ are predominant in normally prospected deposits of this group.

Fourth group: To this group belong small-sized or extended- but extremely interrupted in mineralization- endogenic deposits of valuable ores, with uneven, very uneven and extremely uneven metal distribution in ore bodies. Among them are the following:

- a) schlieren of magmatic deposits of platinum and diamonds;

b) druses of rare-metal minerals and pegmatites;

c) small blocks of rich scheelite ores in skarns;

d) small hydrothermal veins, pipes and druses of rare, radioactive and noble metals;

e) extended hydrothermal veins or ore horizons of deposits of rare, radioactive and noble metals with extremely interrupted mineralization.

Deposits of the fourth group are most difficult to prospect. It is impossible to determine reserves of category A₂ even by shafts with normal intervals between them not exceeding the dimensions of operational blocks. Reserves of category B are established only by shafts within the limits of portions completely cut up into operational blocks. To reserves of category C₁, on the basis of particular ore bodies, belong portions outlined by shafts spaced at distances exceeding the dimensions of operational blocks. Also to category C₁ belong reserves in an area covered only partially by operational blocks and in portions prospected by closely spaced borings adjacent to shafts, at a distance of not more than 50 m. These reserves can also be determined for a part of an ore-bearing structure adjacent to prospected portions by extrapolation, taking into account the low ore-bearing coefficient. Reserves of category C₂ are determined for an entire ore-bearing structure by the mineralization coefficient, which in this case usually has a very small magnitude.

In prospecting deposits of the fourth group mining systems are of decisive importance. Under-ground drilling is employed as an auxiliary method of outlining discovered druses and making new explorations, and also from the surface and from under-ground shafts for marking out the general limits of an ore-bearing structure. In normally prospected deposits of this group, categories C₁ and C₂ predominate.

If all of the above-described approaches to the prospecting of major ore-deposits are assembled, they may be represented in the form of Table 24.

Chapter 2. Description of examples of prospecting major deposits by groups

First Group

Methods of prospecting deposits of the first group are to be seen in the examples of prospecting a number of sedimentary marine deposits of iron, manganese and bauxites.

Prospecting of a sedimentary marine iron deposit: The area of the deposit is made up of

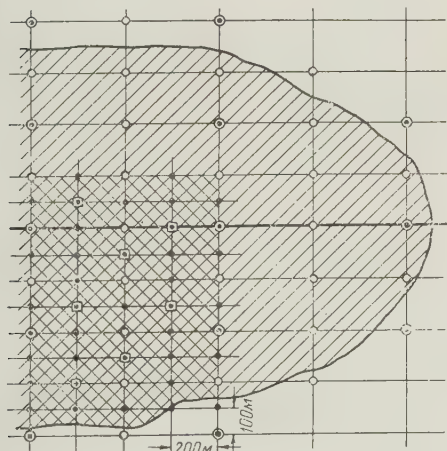
TABLE 24. Systems of prospecting and sample distances between prospecting intersections for various groups of major ore deposits.

| Group | General characterization | System of prospecting | Average distance between intersections | | | | Prevailing system of prospecting | Prevailing category of reserves |
|-------|--|-----------------------|--|---------------|------------------------------------|---|----------------------------------|---------------------------------|
| | | | A ₂ | B | C ₂ | C ₂ | | |
| I | Large deposits of continuous mineralization with sustained form and even metal distribution | Drilling | 100-150 m | 200-300 m | Extrapolation | Extrapolation | Drilling | A ₂ + B |
| | | Shafts | 2 or 3 blocks | Extrapolation | | | | |
| II | Large deposits of continuous or slightly interrupted mineralization usually with relatively uneven metal distribution | Drilling | 20-50 m | 50-100 m | Isolated borings and extrapolation | Extrapolation | Drilling and mine drilling | B |
| | | Shafts | 1 or 2 blocks | 2 or 3 blocks | | | | |
| III | Average-size deposits of varying form of slightly interrupted or interrupted mineralization, with uneven, as well as very uneven, metal distribution | Drilling | - | 40-60 m | 80-150 m | Isolated shafts and extrapolation | Mining and mine drilling | B + C ₁ |
| | | Shafts | 1 block | 2 blocks | | | | |
| IV | Small or extended, but extremely interrupted, bodies with uneven, very uneven or extremely uneven metal distribution | Drilling | - | - | More than 1 block | Extrapolation within the limits ore-bearing of the structure by the ore-bearing coefficient | Mining | C ₁ + C ₂ |
| | | Shafts | - | 1 block | | | | |

Comments:

1. The indicated distances are for the purpose of orientation. Deviation from them based on geological conditions is possible.
2. By the term "block" is understood the normal operational block 30-50 m high and 40-60 m long.

loose Tertiary marine sedimentary rocks (sandstones, loams, clays), including beds of iron ore, crumpled together into gentle folds. In the anticlines the ore bed is eroded and is preserved only in gentle synclinal troughs. The troughs have a length of 6-10 km and a breadth of 1.5 - 2 km. The bed lies at a depth of a few tens of meters and has a thickness of a few meters to 20-25 m; the thickness of the bed increases gradually from the periphery of the trough to the center. It is made up of loose ore of oolitic structure. The deposit is large in size, continuous in mineralization, and regular in form and metal distribution. Prospecting is done by shallow drilling. Preliminary prospecting is usually done in two stages: at first, reconnaissance borings are made along the axis of the trough for 800-1000 m and across the axis for 400-500 m, after which the pattern of borings is reduced to 400 x 200 m. This pattern makes it possible to estimate reserves of category B. In detailed prospecting, the pattern of borings is reduced to 200 x 100 m, and the data obtained on a part of the borings, equal in number to, say, \sqrt{n} (n is the number of borings), are verified by excavations. In this case, it is considered that the reserves may be assigned to category A_2 (fig. 184).



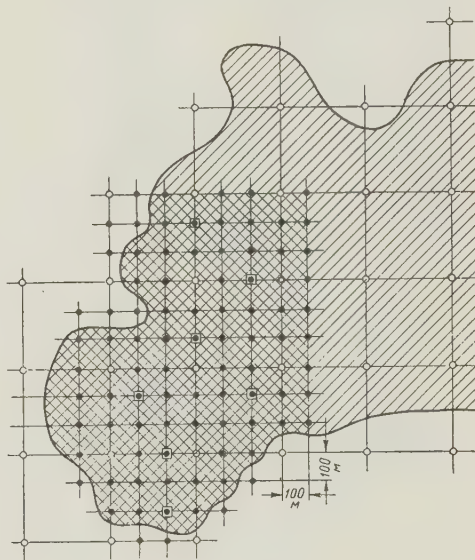
- borings of the first stage of preliminary prospecting on a pattern 800 x 400 m
- borings of the second stage of preliminary prospecting on a pattern of 400 x 200 m (reserves of category B)
- borings of detailed prospecting on a pattern of 200 x 100 m (reserves of category A_2)
- borings controlled by excavations

▨ area of preliminary prospecting

▩ area of detailed prospecting

FIGURE 184. Prospecting of a part of a sedimentary marine deposit of limonite (plan)

Prospecting of a sedimentary marine manganese deposits: The area of the basin is made up of a horizontally lying stratum of soft sedimentary rocks of Tertiary age (sandstones, clays, loams with interlayers of limestone) including a bed of friable manganese ore, mainly of psilomelane-pyrolusite composition. The bed lies transgressively on the uneven surface of Precambrian crystalline rocks. The ore bed is situated at a depth of 15-80 m from the surface. Its thickness varies gradually from 0 to 4-5 and at times 15 m. This deposit, as is the preceding one, is large in dimensions, continuous in mineralization and regular in metal distribution. The thickness of the ore bed is somewhat less sustained, thickening in the depressions of crystalline rocks underlying the ore-bearing stratum. Nevertheless, in its morphological nature the deposit belongs to the class of stable deposits. The deposit is prospected in the preliminary stage by shallow drilling on a pattern of 300x300 m, which makes it possible to estimate reserves of category B. In detailed prospecting the pattern of borings is reduced to 100x100 or 150x150 m, and a part of them are controlled by excavations. This makes it possible to assign the prospected reserves to category A_2 (fig. 185).



- preliminary borings on a pattern 300 x 300 m (reserves of category B)
- borings of detailed prospecting on a pattern 100 x 100 m (reserves of category A_2)
- borings controlled by excavations

▨ area of preliminary prospecting

▩ area of detailed prospecting

FIGURE 185. Prospecting of a portion of a sedimentary marine deposit of manganese (plan)

Prospecting of a sedimentary marine deposit of bauxites: These deposits are usually bauxite beds underlain by limestones and covered over with clayey and limestone rocks. Bauxite beds have a sustained and flat roof, but a complicated floor with swellings, pockets and bay-like deep places. Particularly large complications in the morphology of beds are observed in the surface portions of the deposits. In addition, interruptions forming barren "windows" are encountered in bauxite beds. Thus, marine bauxite deposits have large dimensions, are slightly interrupted in mineralization, and are characterized by even metal distribution, but variable morphology. The last characteristic makes the deposits described close to the second group, and only the most sustained portions of them can be assigned to the first group. In prospecting these deposits, reserves

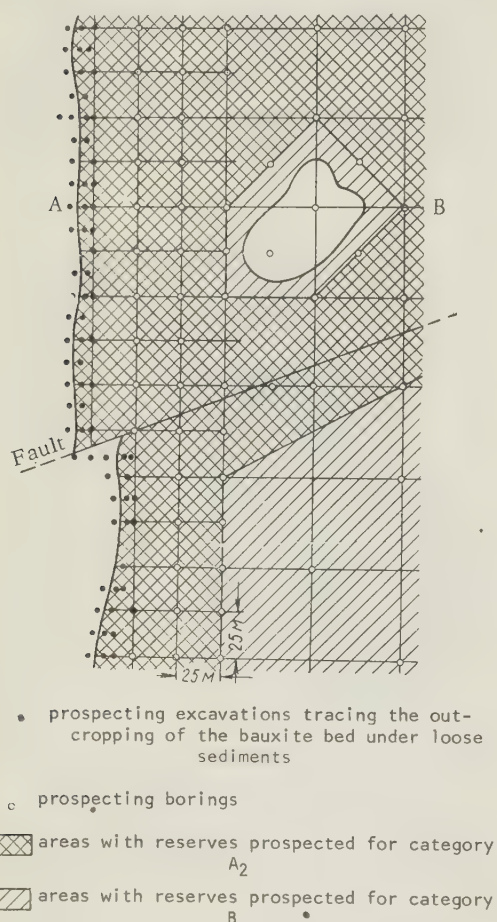


FIGURE 186. Prospecting of a portion of sedimentary marine deposit of bauxites (plan)

of category A₂ may be obtained by core drilling on a pattern of 100 x 100 m and putting a fifth shaft in the center of a square

in case of sharp fluctuations in the thickness of the bauxite bed. Barren "windows" should be outlined by reducing the pattern to 50 x 50 m. Reserves of category B are revealed by a sparser prospecting pattern, but usually not less than 200 x 200 m. The surface portion of the ore bed, which usually has complex morphology, is prospected by a pattern two to four times denser than the pattern by which the whole bed is prospected. Such substantial reduction in the pattern does not complicate the prospecting very much, because to prospect surface portions shallow borings or shafts are employed. An example of prospecting a portion of sedimentary marine deposits of bauxites is indicated in Fig. 186, where the plan of the portion is represented. The cross section is presented in Fig. 187.

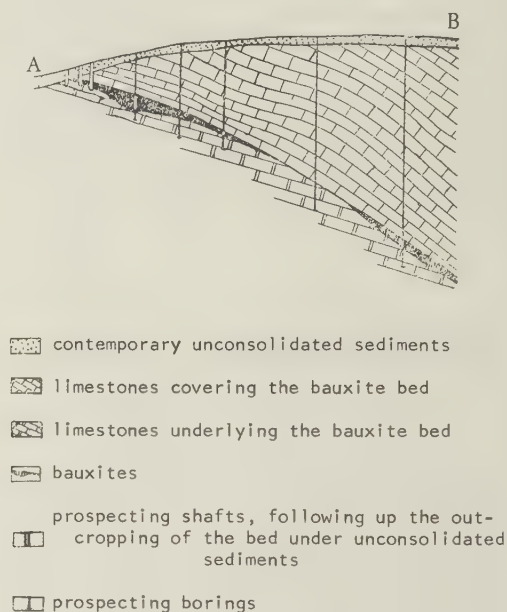


FIGURE 187. Geologic cross section along line AB of a portion of a bauxite deposit, the prospecting plan of which is represented in Figure 186

Second group

A considerable number of heterogeneous deposits go into the second group. Methods of prospecting them may be illustrated by the following examples of investigation:

1. Gently sloping ore bodies situated not far down from the surface, to which are referred, for example, sheet deposits of residual limonitic iron ores and some continental bauxite deposits;

2. Gently sloping ore bodies deep down

from the surface, for example, deposits of copper-bearing sandstones and magnetite ores in skarns;

3. Large equant ore bodies beginning at the surface and extending to considerable depth, for example, veined-disseminated copper ores in secondary quartzites;

4. Steeply-dipping ore bodies, for example, deposits of rich iron ores in ferrous quartzites and lenses of pyritic copper of polymetallic ore.

Prospecting of a sheet deposit of residual limonitic iron ore: The deposit is associated with the weathered crust of serpentine and represents an extensive sheet-like deposit of limonite, covering decomposed serpentine rocks in the form of a sheet. The outlines of the deposit are continuous, but inside it are found portions of barren rocks. The bottom of the deposit is uneven, with many depressions and projections of serpentine. The iron content, although varying from 20 to 50 percent, is nevertheless comparatively uniform. Thus, this deposit is large, slightly interrupted, relatively uniform in metal distribution in the ore body and variable in morphology. The prospecting of it, as shown in Figures 188 and 189 was accomplished by means of pits and shallow borings along lines crossing the trend of the deposit. The prospecting pattern of 100 x 100 m assures the determination of reserves of category B. Reducing the pattern to 50 x 50 m and, in complex portions, to 25 x 25 m, makes possible the estimation of reserves of Category A₂.

Prospecting an ancient alluvial bauxite deposit: Ore bodies of ancient alluvial bauxite deposits have the shape of a ribbon, lying horizontally at a depth of 10-20 m, extending hundreds of meters in length and 60-200 m in width. Such deposits are underlain by clays and overlain by sandstones and sandy loams. The most complicated part of the structure of the deposit is its shape due to important variations in the thickness of the ore body. This deposit, as well as the preceding one, is large, slightly interrupted, relatively regular in metal distribution in the ore body, and variable in morphology. It is prospected, as shown in Figures 190 and 191, by lines of shallow borings crossing the trend of the deposit. With a distance of 40 m between the lines and between the borings, reserves of category B are determined. Reducing the distance between lines to 20 m and between the borings in the line to 10-15 m makes it possible with control excavations to determine reserves of category A₂. It must be noted that extreme closeness of the prospecting pattern, both in this case and partly in the preceding one, is required, not only for outlining the ore deposits, but also for separating the areas of different grades

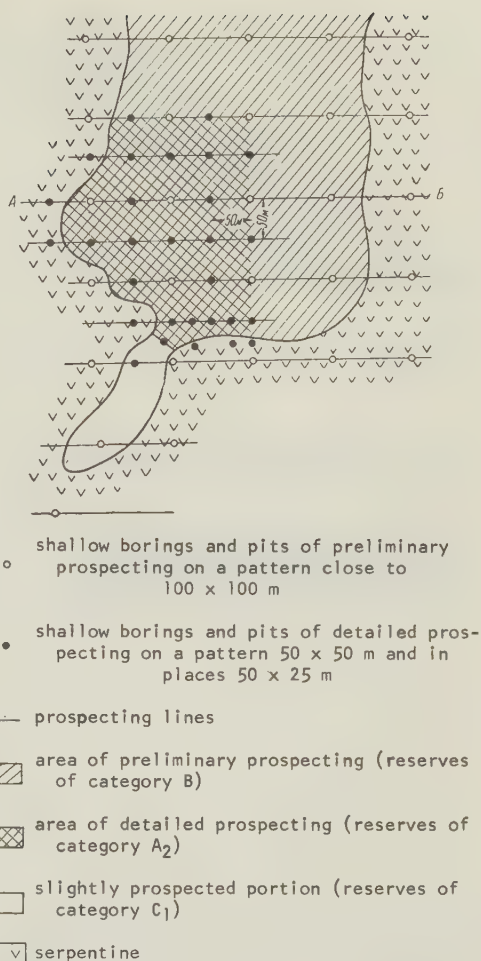


FIGURE 188. Prospecting of a portion of a sheet-like deposit of lateritic limonite, from serpentine (plan)

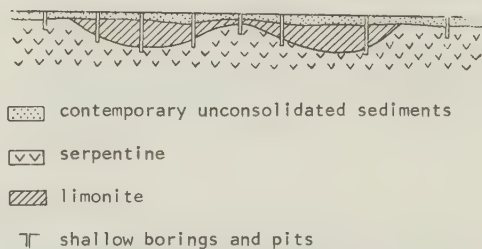


FIGURE 189. Geologic cross section along line AB of the portion of sheet deposit of lateritic limonite, the plan of which is represented in Figure 188

of ore within them. This is not reflected substantially in the organization and cost of prospecting, because ore bodies lying near the surface of the earth may be prospected quickly and cheaply by means of shallow pits, excavations or borings.

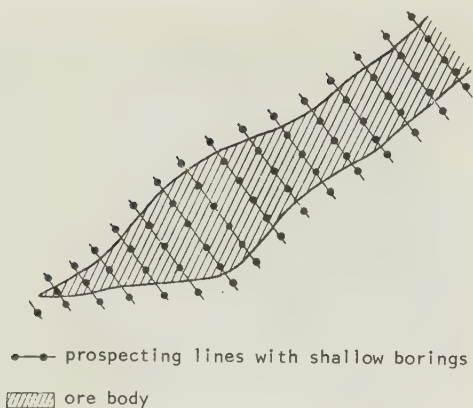


FIGURE 190. Prospecting of a portion of an ancient alluvial deposit of bauxites (plan)

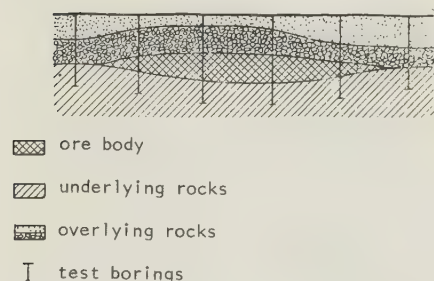


FIGURE 191. Geologic cross section of a portion of an ancient alluvial deposit of bauxites

Prospecting a magnetite deposit in skarns: This deposit was formed as a result of the effect of the intrusion of high-silica rocks on limestones and tuff-effusives. It represents an extended sloping deposit of skarns with magnetite up to 120 m thick. The structure of the deposit is complicated by dikes of diorite, microgranite and porphyry and by numerous faults which cut it up into a series of blocks displaced 10-50 m. To a depth of 40-50 m from the surface the deposit is made up of oxidized martitic and semi-martitic, sulfur-free ores. The primary ore, situated below, is composed of magnetite with

a certain amount of sulfides. In the area of the deposit a cover has been formed of loose rocks and boulder-like ores from 0.5 to 30 m thick (fig. 192). The deposit is large, practically continuous, relatively even in distribution of iron and other elements which determine the grade of ore, but it has a complicated morphology as a result of the abundance of dikes and faults which cut up the ore body.

To prospect such a deposit core drilling is employed. With average dimensions of the drilling pattern of 100 x 100 m, reserves of category B are determined. In areas adjacent to operating pits, within one or two lines of borings, reserves may be assigned to category A₂. They may be assigned to the same category where the pattern is reduced to the average dimensions of 50 x 50 m with control excavations. For the latter it is possible to utilize separate excavations, with which boulder-like ores are prospected on a pattern of 50 x 50 to 100 x 100 m, by deepening them. It must be noted that in prospecting the deposit described, it is not always possible to hold strictly to a set pattern of borings, on account of the necessity of undercutting and following up dikes and faults which cut through the ore deposit.

Prospecting a deposit of copper-bearing sandstones: In this deposit, as in other deposits of this type, the ore bodies are extended beds and particular interlayers of sandstone, containing a dissemination of copper sulfides and lying in a suite of sedimentary rocks represented by conglomerates, argillites, sandstones and cherts (fig. 193).

The ore deposits are situated as far down from the surface as 200 m. The main ore deposits extend for hundreds of meters, and even kilometers, and are accompanied, both on the hanging-wall and the foot-wall by parallel ore bodies of lesser dimensions. The thickness of the ore-bearing beds does not vary widely, although there is a considerably sharper change in the content of copper, and especially in that of lead, which is present in some ore bodies.

Thus, the principal ore bodies of this de-

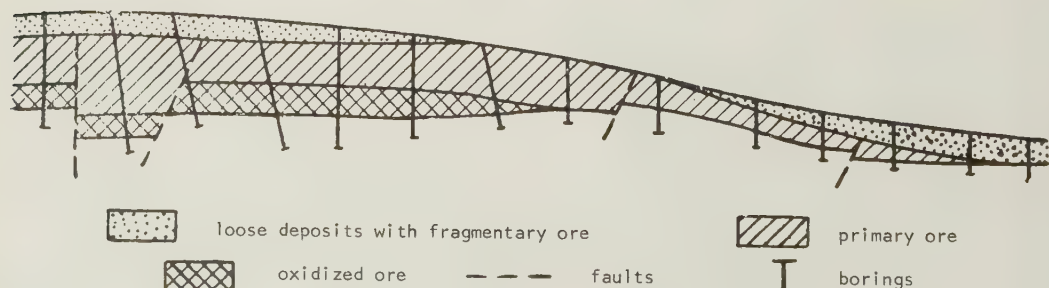


FIGURE 192. Cross section of a part of a magnetite deposit in skarns

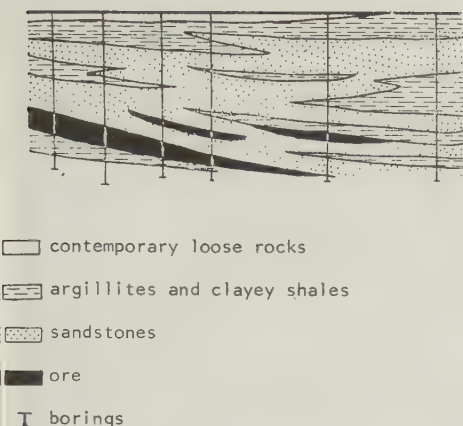


FIGURE 193. Schematic geologic cross section of a part of a deposit of copper-bearing sandstones

osit are large in size, uneven in mineralization, comparatively stable in morphology and regular in the distribution of the metal in them.

In determining the density of the prospecting pattern it is necessary to take into account the characteristics of the structure and composition, not only of the main ore bodies, but also of the secondary deposits, which, as has already been indicated, have smaller dimensions. These deposits are prospected principally by core drilling. It has been established in the practice of prospecting that a drilling pattern close to 100 x 100 m makes it possible to determine reserves of category B. When the pattern is made twice as close, i. e., 50 x 50 m, and a shaft is dug for taking large samples of ore necessary for technological studies, the reserves are assigned to category A₂.

Prospecting of stratified deposit of copper-nickel sulfide ores: This ore deposit represents a so-called "bottom" deposit of disseminated copper-nickel sulfide ores of immiscible liquid-magmatic origin associated with the lower part of a gently sloping intrusion of gabbro (fig. 194).

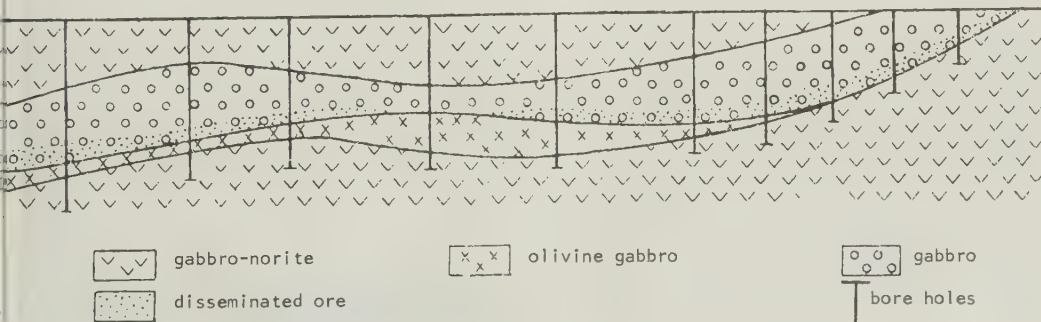


FIGURE 194. Section through a layered deposit of disseminated copper-nickel ore

The deposit stretches continuously to a great distance, but inside of it there are interruptions forming widely separated barren "windows". The variations in thickness are unimportant. In regard to the content of copper and nickel, however, it can be said that it, too, is uniform in the plane of the deposit, but not uniform vertically through the thickness of the ore body.

The deposit is prospected principally by core drilling. The pattern of corings of 100 x 100 m assures determining reserves of category B. A pattern of core drilling of 50 x 50 m in portions adjacent to shafts, or verified by shafts specially for this purpose, makes it possible to outline ores of category A₂.

Prospecting of a veined-disseminated deposit of copper ores in secondary quartzites: This ore deposit is typical for the class indicated and represents a large deposit of finely veined and disseminated ores among silicified and sericitized acid effusive rocks and granodiorite-porphyrries. The deposit outcrops at the earth's surface, being covered in places only by a thin train of deluvium. Its area in the plan is about 1 km². As indicated by prospecting, the deposit possesses distinct secondary zoning. A zone of oxidized copper ores is developed from the surface to a depth, on the average, of 20-30 m. Still lower, also on the average, for 25-35 m there is a zone of leached rocks with uneconomic copper content. Under it, for 120-150 m extends a zone of secondary chalcocite ores which constitute the basic value of the deposit. Under the zone of secondary sulfide ores is a zone of primary sulfide ores, economic on the periphery of the deposit and uneconomic in the center of it (fig. 195). The boundaries between the zones are rather sinuous, especially between the zone of oxidized ores and the leached rocks. Variations in the copper content within the configurations of the economic ores are not great.

Thus, the ore body is large and continuous, not counting the interval of the leached zone, which separates the economic zones of oxidized ore and the secondary sulfide ore. The distribution of metal in the ore body is nearly

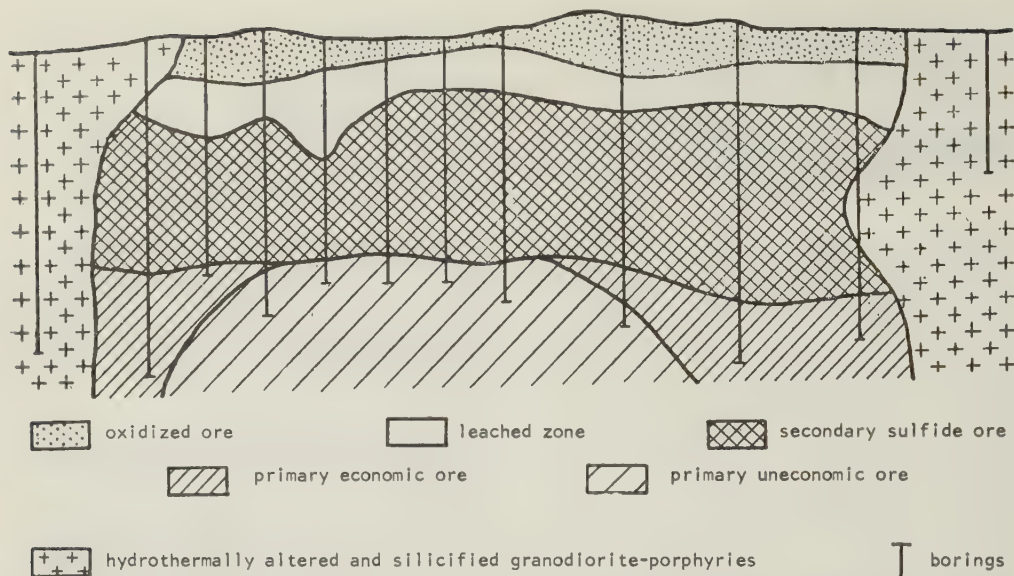


FIGURE 195. Schematic cross section of a deposit of veined-disseminated copper ores in highly silicified igneous rocks

uniform. The most complicated element is the surfaces which separate the secondary-ore zones and mainly determine the choice of prospecting method and density of pattern. Their position and morphology should be determined with special care in the course of prospecting, since this kind of deposit is worked by the open-pit method, which requires a knowledge of the exact limits of commercial ores in horizontal sections for 10-15 m, i. e., the distance equal to the height of the ledge being worked.

These deposits are usually prospected by drilling. A system is used which combines cable drilling with core drilling, or a system of core drilling. In the first case the bulk of borings are made with cable rigs, assuring large tests important for the precise determination of the grade of ore, and a certain number of borings are made by core drills, assuring the taking of samples (cores) for the purpose of making up exact geologic cross sections and studying the mineralogical composition of ore. In the second case all borings are made by core drills. Where there are rigs for deep cable drilling the first method is preferable. A drilling pattern of 100 x 100 m assures the determination of reserves of category B. The most widely employed method of making the pattern closer is to make supplementary borings in the center of a square, creating thus another square pattern of borings with a distance between them of about 60 m and turned at a 45 degree angle to the original pattern (fig. 196). If with this arrangement a shaft is sunk for taking large batches of ore from all zones of the deposit for technological testing, then the prospected reserves belong to category A₂.

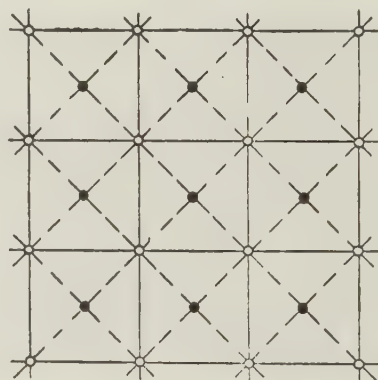


FIGURE 196. Conversion of a square prospecting pattern of the first stage to a square pattern of the second stage by sinking supplementary shafts (or borings) in the center of the square

The above-described system of prospecting veined disseminated copper ores in silicified rocks is analogous to the case of a deposit situated in a locality with even relief. If deposits of this type are located among mountains and lie in a section having extremely broken relief, then, in prospecting at least their upper parts, galleries and drifts are used, which cut up the deposit in mutually perpendicular directions for 40-60 m. However, prospecting these deposits with borings is in all cases the most expedient.

Prospecting of a steeply dipping lens-shaped deposit of pyritic ore: The ore body has the shape of a steeply-dipping lens, situated between albitophyres and their tuffs, breccias and

metamorphosed variations transformed into quartz-sericite schists. The upper part of the lens is strongly oxidized and transformed into an iron cap. The primary ore is made up of massive copper-containing pyrites and disseminated ores with uneven copper distribution in them. The ore body is large, continuous, comparatively stable in respect to morphology, but uneven in metal distribution.

Its prospecting is shown in Fig. 197. After

to determine reserves of category B for large and medium lenses (for small lenses, reserves C_1). Reserves of categories A_2 and A_1 are usually determined after uncovering the ore body, by means of an operational shaft in the process of preparing the deposit for development, and during development. Here, the greatest importance for prospecting by shafts is attached to cross drifts, by which a thick ore body is cut up at every horizon through an average of 40 m. Reserves thus prospected

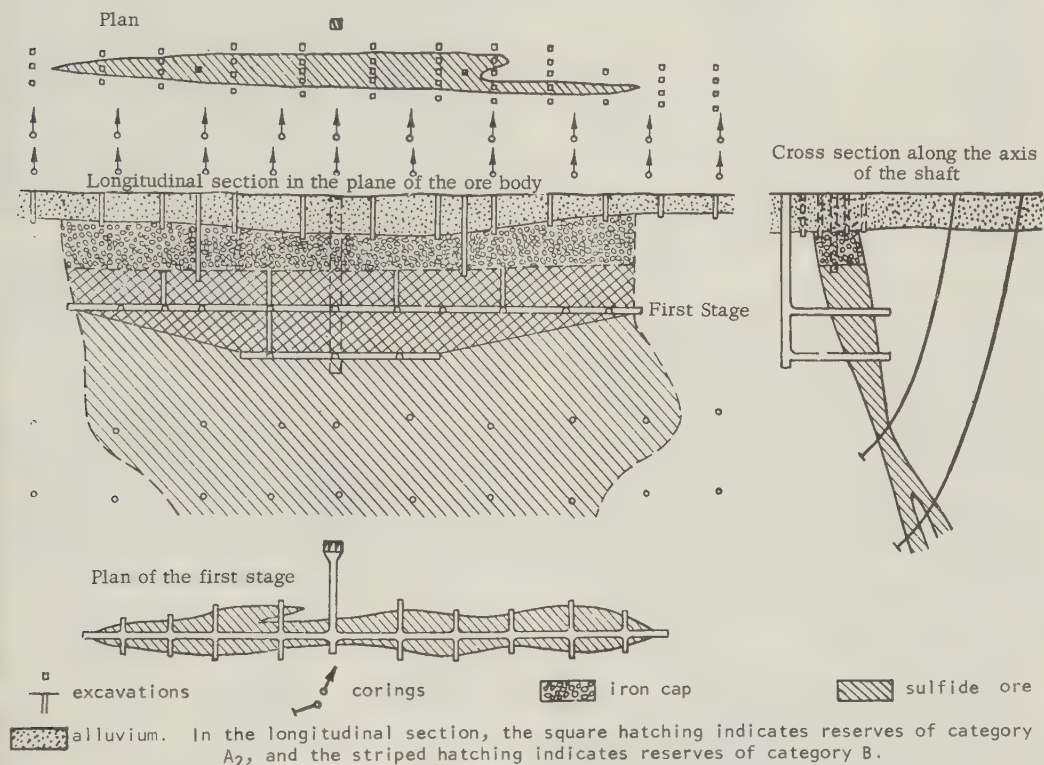


FIGURE 197. Scheme of prospecting a lens of copper pyrite ore

tracing and outlining the outcropping of the ore body under the loose sediments by a line of excavations laid out at distances of 30-50 m from each other, 1-2 excavations were dug to intersect the iron cap and determine the grade of primary sulfide ores. At the same time, the content of gold and silver is determined over the entire section of the iron cap. In this kind of deposit these metals tend to concentrate in the lower part of the cap. It is good to drive cross drifts from the excavations to determine the thickness of the deposit in the primary zone.

After that, prospecting of the zones of primary ores was done by inclined core drilling, intersecting the ore body both along the strike and along the dip through 50-60 m. Such a pattern of prospecting borings makes it possible

may already be referred to categories A_2 and A_1 . The scheme for prospecting a group of copper-pyrite lenses is shown in Figure 198.

Third group

The most typical representative of the third group are the hydrothermal veins of non-ferrous metals, as well as the largest and simplest veins of noble and rare metals. Besides, as has been indicated above, in this group are found veins and blocks of chromitic, ilmenite-magnetitic and copper-nickel magmatic deposits, as well as the majority of the deposits of rare metals in skarns and complex ore bodies of lateritic silicate nickel deposits.

Prospecting a hydrothermal ore vein: The ore



FIGURE 198. Cross section along a series of pyrite lenses explored by shafts and borings (according to G.G. Gudalin and F.I. Kovalev). Letters indicate the reserve categories.

vein presented here by way of an example is typical, so to speak, of an average hydrothermal vein. It is a few hundred meters in length and its thickness varies from 0 to 2 m with an average of 0.75 m. The vein is broken into large parts by an occasional fault. Fluctuation in metal content along both the strike and dip, although not very sharp, has considerable range, which sets the variation coefficient at 115 percent. Consequently, we are concerned in the present case with an ore body of average dimensions, continuous in mineralization, variable in morphology and very uneven in metal distribution.

The general prospecting scheme is shown in Figure 199. A continuous trench is cut along the head of it from the surface, following the vein. This method of following up a vein from the surface is preferable to intersecting the vein by a succession of trenches laid out at right angles to its strike. It makes it possible to trace the vein step by step, to test it in detail, and to locate all breaks displacing the vein.

Deep down, the vein is revealed from a prospecting shaft at two horizons by crosscuts, from which drifts are cut along the strike of the vein, and from which in turn are cut raises. Such a system of detailed prospecting for the upper part of a deposit makes it possible to trace a vein continuously, to determine the locations of breaks caused by faults, to establish their displacement, to discover and outline the tectonic blocks into which a vein is divided by faults, to expose the enriched segments in the body of the vein [shoots], and to determine the slope of its boundaries.

Some corings are made below the exploratory workings for 60-120 m. In the case of very uneven metal distribution in the vein, these borings cannot give satisfactory information on the grade of the deposit, but they do fix the extent of the vein to a certain depth.

As a result of prospecting operations, reserves within the limits of operational blocks not broken by faults are assigned to category A_2 . The remaining part of the reserves, as revealed by workings, are assigned to category B. Reserves of category C_1 are estimated down to the level of the lower boring which undercuts the vein.

Prospecting of a chromite deposit: According

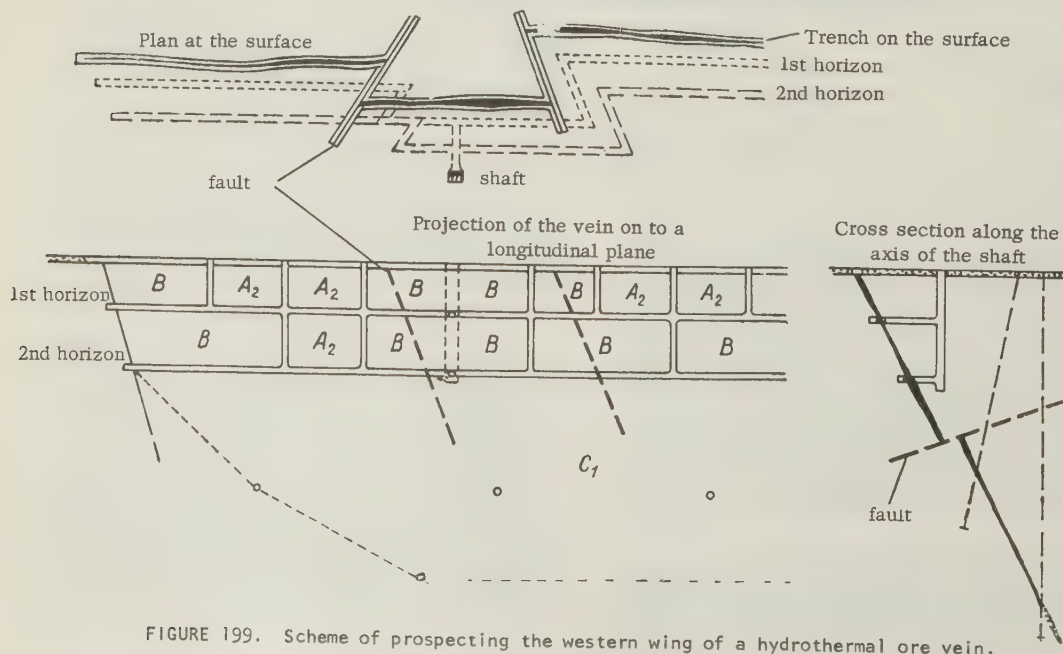


FIGURE 199. Scheme of prospecting the western wing of a hydrothermal ore vein.

to data of A. G. Betekhtin, G. M. Krasnovskii, A. A. Rudin and P. M. Tartarinov (1941), the segment described is located in the central part of a gabbro-peridotite serpentinized mass. The ore bodies have the shape lenses, replacing each other coulisse-like along both the strike and dip. They are broken into tectonic blocks by faults, which seriously complicate the understanding of the morphology of the ore bodies and makes their prospecting difficult. The procedure for prospecting this and other similar deposits depends greatly upon the study of the post-ore tectonics, without which it is impossible to direct prospecting operations correctly or to interpret their results correctly. The upper part of the ore lenses is opened by galleries and shafts, and they are bored out beneath by inclined core drilling (fig. 200). Severe fracturing of the ore bodies compels close drilling profiles with borings 10-20 m apart and with intersection intervals of ore bodies along the dip also of 10-20 m.

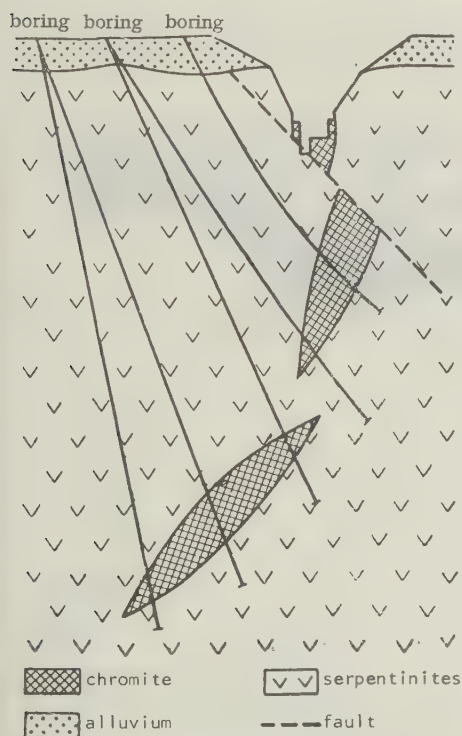


FIGURE 200. Cross section of a chromite deposit prospected by core drilling

Prospecting of a scheelite deposit in skarns: The skarn deposit represented in Fig. 201 is a typical formation of this group of ore deposits. At the contact of granodiorites and limestones lies a thick and extended deposit of skarns, from which apophyses branch off in the direction of the hanging wall. The distribution of scheelite in skarns is uneven. Thus, this deposit is average in size, complicated in structure, and has uneven metal distribution in the ore.

Its upper part is prospected by mining operation including galleries and drifts which pass through the thick part of the deposit with cross-cuts for 15-20 m, as well as independent drifts following particular apophyses of the hanging wall. Lower, in the deep part, the deposit is prospected by core drilling with average intervals of 40-60 m.

Mining operations make it possible to reveal a certain number of reserves of category A_2 , but principally of category B. Borings make it possible to outline reserves of categories B and C_1 .

Prospecting a complicated deposit of lateritic silicate-nickel ores: In Figure 202 is represented an example of the geologic structure of such a deposit and its prospecting by using a dense pattern of borings. The ore body is made up of nickel-containing nontronites lying on decomposed serpentine and covered over with ochres and clays.

This ore body is distinguished from ordinary nickel silicate deposits of the open or closed type by its variable morphology and more uneven metal distribution in the ore. Its morphological instability is due, not merely to substantial fluctuations in the total thickness of the ore body, but principally to the frequent alternation in it of different grades of ore and barren rock.

The ore body is average in dimensions, interrupted in mineralization and has unstable morphology and uneven metal distribution.

Due to the fact that the ore deposit described is worked by the open-pit method, it is prospected entirely by vertical core drilling on a close pattern with a certain number of control excavations. A pattern of borings 20 x 20 m makes it possible to outline reserves of category B, which are prerequisite for this type of deposit in setting up a plan of development. Reserves of category A_2 are revealed principally in the process of exploitation, and, in the opinion of A. A. Glazkovskii (1949), they can also be prospected by core drilling with a pattern 20 x 10 or 10 x 10 m.

Fourth group

The most complicated deposits to prospect, usually of small dimensions, belong to the fourth group.

Systematic prospecting of these deposits, apart from exploitation, is entirely infeasible. They are usually prospected by using a large number of closely spaced underground shafts, a considerable part of which have been used in exploring for ore bodies underground, and a smaller part, in entering these bodies for subsequent immediate extraction. Thus, in

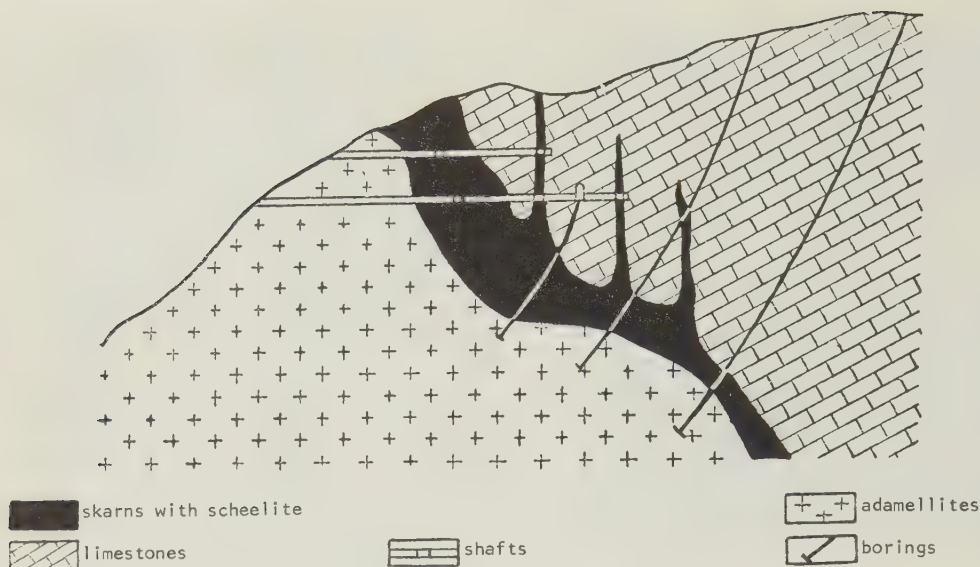


FIGURE 201. Prospecting of a scheelite deposit in skarns (transverse section)

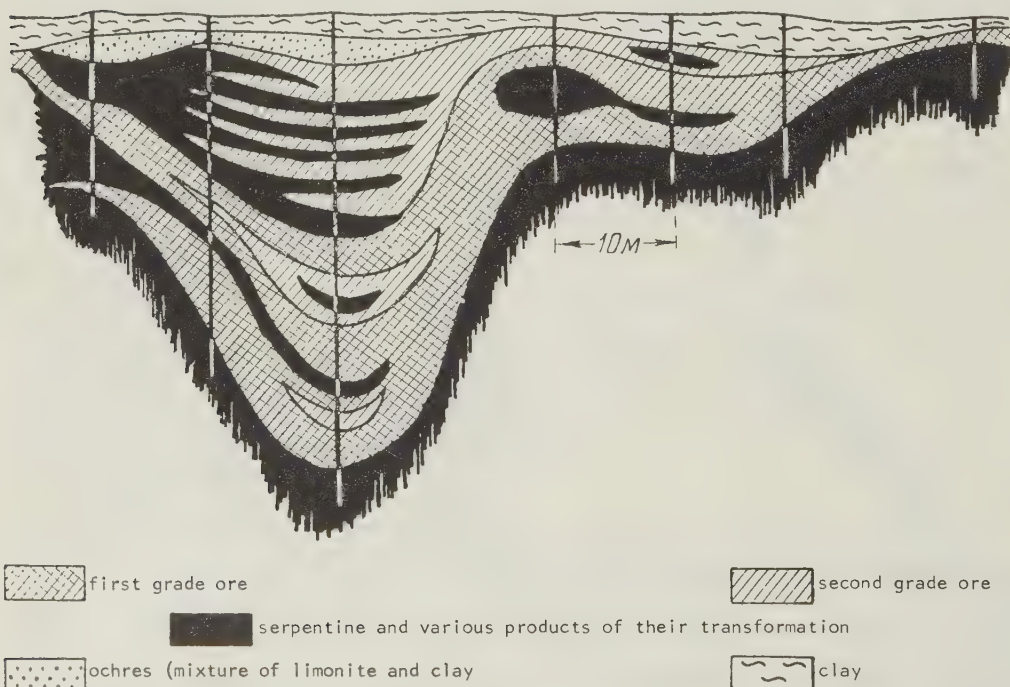


FIGURE 202. Prospecting of a complex ore body of a nickel silicate deposit (cross section)

this case, prospecting, as it were, blends with exploitation and is realized essentially through excavation with concomitant outlining of the ore body by shallow borings and shafts required in the process of its development. Drilling from underground workings and from the surface is employed as an auxiliary operation for establishing the outlines of the ore-

bearing structure and the search for isolated pockets. Reserves of category A_2 are not established in prospecting these deposits, even by mining operations. A certain amount of conditional reserves of category B may sometimes be determined by mining operations, but, in the main, deposits of the fourth group are characterized by reserves of categories C_1

and C2.

Only deposits of very valuable ores can stand huge mining operations for the discovery of small ore bodies. Among ore deposits of this group the following may be indicated:

1) pipe-shaped deposits; 2) small and rare pockets associated with a definite ore structure (bed, vein, fracture, etc.), 3) ore bodies broken up into small blocks by a close system of faults, and 4) small ore bodies scattered at random.

Narrow, capricious, sinuous pipe-like deposits: These may, for example, be represented by pipes of polymetallic ores in limestones. These small pipes of very rich polymetallic ores, sometimes encountered in groups, have an average cross section of 0.6-1.5 m, bending in complex fashion, branching, shrinking to the size of a bottle neck and swelling to tens of meters, and sinking far into the limestones which contain them (fig. 203).

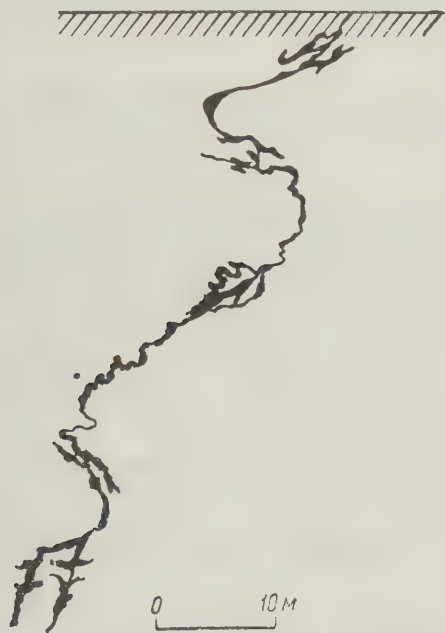


FIGURE 203. Cross section of a thin pipe of polymetallic ore

Such deposits can be prospected most simply by digging an inclined shaft-like passage following the pipe. Usually in digging the shaft the entire ore body is extracted. However, capricious bends in the pipes most frequently exclude the possibility of such a passage. Then prospecting is done by means of a vertical shaft located at the surface outcropping of the pipe, and by successive undercutting of the pipe from the shaft at close horizons 10-15 m apart. Large intervals between the horizons render the exploration of the ore pipe difficult.

Even on close horizons "catching" the pipe is not an easy matter and requires a considerable number of drifts and underground borings which are employed to intersect the pipe. Prospecting of such pipe-like deposits is simplified where their spatial position is controlled by definite geological elements such as the intersection of a stratum and a joint or of two joints.

Small ore pockets: These, associated with a definite ore structure, may be represented, for example, by a bed of silicified limestone with sporadic accumulations of cinnabar (fig. 204) or a quartz vein with rare and small ore segments (fig. 205). Prospecting in this case is

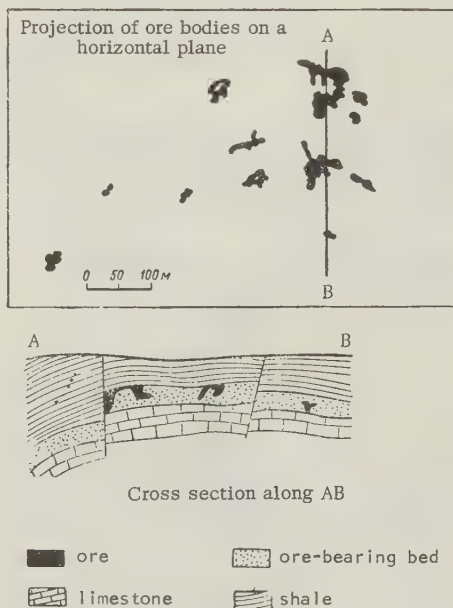


FIGURE 204. Distribution of a cinnabar druse of quartzitized limestone

accomplished by digging closely spaced mutually perpendicular passages exposing the ore pockets, which following this are mined immediately. The ore-bearing plane (bed or vein) within whose limits the ore pockets are scattered serves here as a controlling guide which facilitates prospecting. But the small dimensions of the pockets and the extreme discontinuity of mineralization permit the decision of prospecting problems only by the above-described method. Here the minimum distance between test shafts is determined by the diameter of the smallest pocket, the pursuit of whose discovery justifies spacing the shafts as close together as its dimensions. This distance between underground shafts may be made wider in case of the employment of auxiliary drilling for the purpose of opening up a part having ore pockets. However, it is altogether inapplicable for cases of rich but

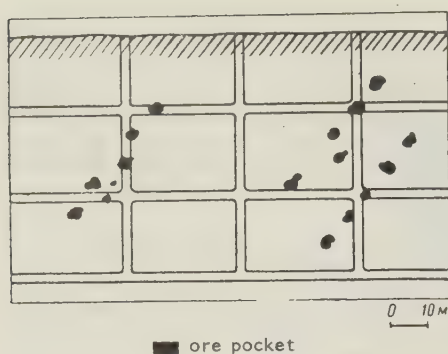


FIGURE 205. Distribution of ore pockets in quartz veins

scattered ores. In this case the coring may pierce the contour of the pocket and not determine the ore.

Ore bodies broken into small parts by faults: A vein-like deposit of chromite, shown in Figure 206, can serve as an example of this case.

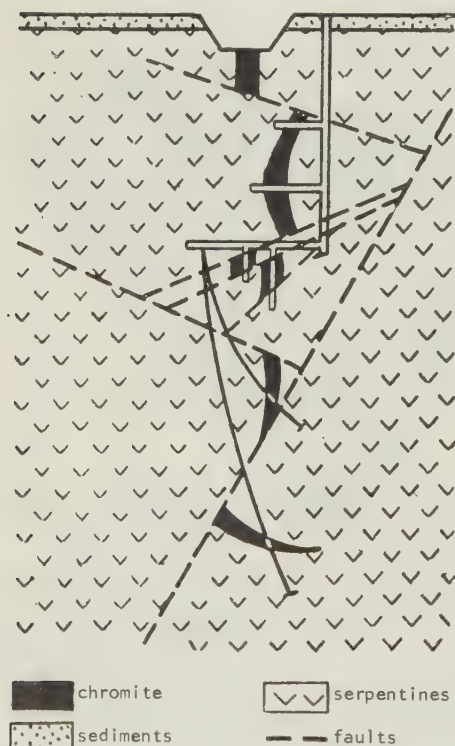


FIGURE 206. Prospecting of a chromite deposit broken up by frequent faults (cross section).

Prospecting of such deposits is possible only with a close pattern of test shafts and accompanying borings, based on a careful study of post-ore tectonics. Moreover, it is necessary

to try to explain the genetic and spatial relationships of displacing faults, the sequence of their development, and the regularities in extent of displacement. Only painstaking study of post-ore fracturing makes it possible to direct the prospecting of such ore deposits judiciously.

Small, scattered, erratic ore bodies: These are the hardest to prospect. To this group belong schlieren of platinum-bearing chrome spineloids in dunites, and pockets of piezo-quartz in quartz veins of complex form. In these cases, even a system of closely spaced shafts can assure the exposure of only some portion of the ore bodies. Only a continuous excavation of an entire mass, including ore pockets, can assure their complete registration. But such excavation in many cases is not feasible. It should be remarked that in a thorough study of the geologic structure of sections similar to those mentioned, it is often possible to establish patterns in the spatial distribution of ore pockets "of an erratic order." When this is true, the direction of prospecting is made easier, and approximates in its conditions the exploration of ore pockets associated with a definite ore structure.

Chapter 3. Prospecting of placer deposits

Systematization of placers

Placer deposits are formed from heavy ore minerals, stable under oxidizing conditions at the earth's surface. Accordingly, the most widely-occurring placers are those of gold, platinum, tin (cassiterite), tungsten (principally, wolframite), titanium (ilmenite, rutile, and others) and monazite. In respect to mineral-ore composition, placers may be homogeneous or complex. The more frequently encountered placers are homogeneous and those less frequently encountered are complex. To the latter belong gold-platinum placers, gold-monazite placers and tungsten-cassiterite placers.

In respect to formation conditions, the following main types of placers are distinguished:

- 1) eluvial - covering a dissemination area of mother ore-bearing formations;
- 2) diluvial, - displaced down slope, to one side, from mother ore-bearing formations;
- 3) proluvial - deposits of intermittent streams at the base of mountains;
- 4) alluvial (stream deposits) - formed during selective deposition on account of the re-washing of fragmentary material containing particular ore minerals. Among stream deposits, four types are distinguished: slope, channel, valley and terrace;
- 5) lakeshore and seashore - due to the ac-

accumulation of heavy ore minerals in the shore zone during the selection of terrigenous material carried down to lakes and seas.

The general scheme of distribution of all types of placer deposits, except proluvial and shore deposits, is presented in Figure 207.

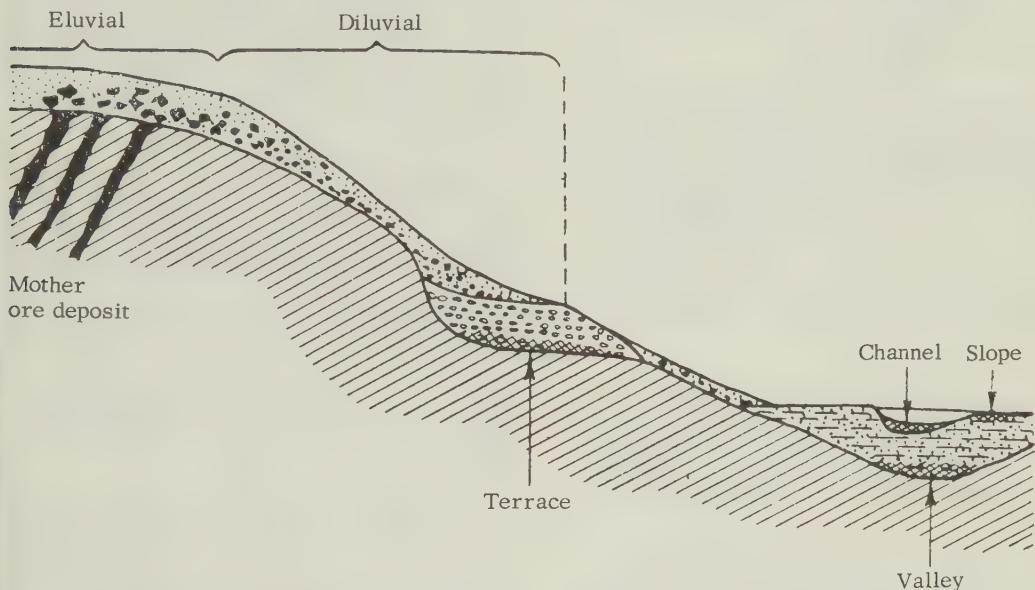


FIGURE 207. Scheme of placer distribution (cross section of a river valley)

Yu. A. Bilibin (1938) distinguishes among river deposits simple placers and complex placers. Simple placers have one ore stratum lying on a bed rock (fig. 208a) and complex placers consist of several ore strata, a part of which is underlaid by a false bed (fig. 208b).

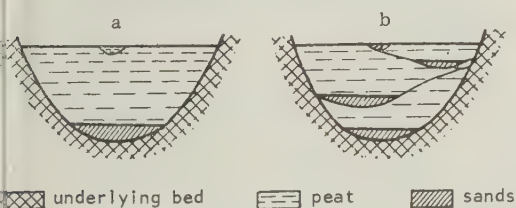


FIGURE 208. Schematic cross section of a simple (a) and a complex (b) placer deposit (according to Yu. A. Bilibin)

In respect to time of formation and position in the cross section of sedimentary rocks, placers are divided into young-Quaternary (contemporary), which are open, and older placers, often covered by recent sediments, and, in this case, being covered or buried. Pre-Quaternary buried placers are by some geologists also called mineral deposits.

In prospecting placer deposits, in addition to determining their dimensions and grade in respect to metal content, it is imperative to

study the following special questions, important for the economic evaluation of these deposits: 1) composition and properties of the ore bearing strata and the material covering them, 2) nature of the bed, and 3) frost.

Study of the composition and properties of

the ore-bearing strata (sands) and the material covering them [peat] has substantial importance both for understanding the laws of distribution of the valuable mineral, and, above all, for determining the conditions for working the deposit. For these purposes it is necessary to determine the thickness of both the sands and the peat, the ratio of their thicknesses, and the change in this ratio in different sections of the placer. The lithologic and mineralogical composition of sands and peat and their degree of induration and scouring is determined.

Investigation of the nature of the bed is also important, both for the purpose of explaining its influence on the concentration of valuable minerals, and for determining any special features of the development of the placer. One should determine the rock composing the underlying bed, the morphology of its surface (smooth, fluted, with ledges, projections, depressions, etc.), and where laminated and shaly rocks compose the bed, one should determine, in addition, the orientation of lamination and shaliness with respect to the trend of the deposit.

If the placer is in a zone of permafrost, one should study the frozen condition of the sands and peat to determine the continuous of spotty nature of the frost, or the presence of watery and water-free taliks in the buried ice.

In the majority of cases placer deposits are prospected by lines placed across the deposit. Prospecting is done by means of excavations or pits, which make it possible to obtain a considerable amount of material absolutely indispensable in determining the amount of valuable mineral in sands, often found as discreet grains throughout considerable volume of the rock. Excavations are placed in a long line athwart the trend of the placer.

Where there is a large flow of water into an excavation, which is quite natural in prospecting river deposits, these operations are done in the winter, when the ice solidifies the water on the sides of the excavation, sheathing it with a kind of ice armor. If prospecting must be carried on in the summer, then, in case of very great influx of water, it is necessary to turn to prospecting by drilling, which gives less precise information on the content of valuable minerals in sands.

If there are few boulders, drilling is done with units of the Empair or Nev'ianskii type of drill. If there are many boulders, the only possible method of prospecting is drilling by the cable method, using the largest possible diameter.

A scourge of much prospecting of placer deposits is the tendency to stop the digging or drilling short of reaching bed rock. Strong measures should always be taken to eliminate completely such unfinished shafts and borings, and to assure that all of them are dug through to the bed-rock, to intersect the lower part of the placer which is where the most important accumulations of ore bearing sands are found.

Prospecting of placers

Prospecting of eluvial, diluvial, as well as proluvial deposits: This is realized by lines laid across the trend. Where the thickness of the eluvial and deluvial cover is small, not exceeding 4-5 m, prospecting may be done by trenching. Where the thickness is considerably greater, it is done by excavations, pits, and much less frequently by borings, on a pattern of distances between shafts or borings of 40-20 m.

Prospecting river deposits: This is usually done by several methods. In locations which show the most promise on the basis of geological, geomorphological, and panning data, isolated shafts or exploratory lines of shafts are made first. Such reconnaissance intersections, depending on the character of the valley, are carried out at distances of from 4,000 to 500 m and seldom less. In case of positive results from this stage of the study of a placer, preliminary prospecting is organized, employing lines of excavations or borings across the trend of the valley (but not of the river!). Usually in

this case reserves of categories B and C are obtained. Finally, detailed prospecting is carried out, by determining reserves of category A₂. Detailed prospecting is conducted, using close spacing of lines of shafts or borings only in those parts of the valley where preliminary prospecting has outlined the economic parts of the deposit. Usually it is the pattern of lines that is made closer. Less frequently are the shafts or borings in the lines of preliminary prospecting spaced closer. An example of a general scheme of prospecting a valley deposit is presented in Figure 209.

The distances between the lines and between the shafts or borings in the lines depends basically on the dimensions of the placer and the degree to which the productive horizon holds out in thickness and content of valuable mineral.

Placer deposits are divided into three groups, according to the degree to which the productive zone holds out, the distribution of valuable minerals, and other features. The group to which a placer belongs is determined by the required frequency of prospecting lines and of shafts or borings in the line.

First group contains well sustained placers characterized by relatively even distribution of valuable mineral and by well-sustained breadth and thickness throughout the entire length of the prospected segment. The productive horizon in its lithographic composition is sharply delimited from the overlying layers. The grains of valuable mineral are rounded and relatively even in size. The bed of the placer is even, with a slight gradual slope. The first group includes placers of relatively large rivers having a broad, well-developed course. The majority of dredged placers of the Urals, the Yenisei River, the Amur region and other regions go into this group.

Second group contains sustained placers, characterized by a less even distribution of valuable mineral, but comparatively well-sustained thickness of stratum and peat. In this case, the bed can hardly be differentiated in its composition from the overlying loose sediments and is distinguished only by test data. The grains of valuable mineral may have varying degrees of roundedness, and native metal and large crystals may be encountered. The bed of the placer is uneven and has a relatively steep slope. To this group also belong well sustained placers, but with a sharply uneven bed (fluted with pockets, depressions and sink holes). This group is represented by channel, valley and terrace placers of gold, platinum, tin and tungsten, situated predominantly in medium-size valleys, and also by some of the largest diluvial deposits.

Third group contains unsustained and pocket-type placers with uneven distribution of valuable

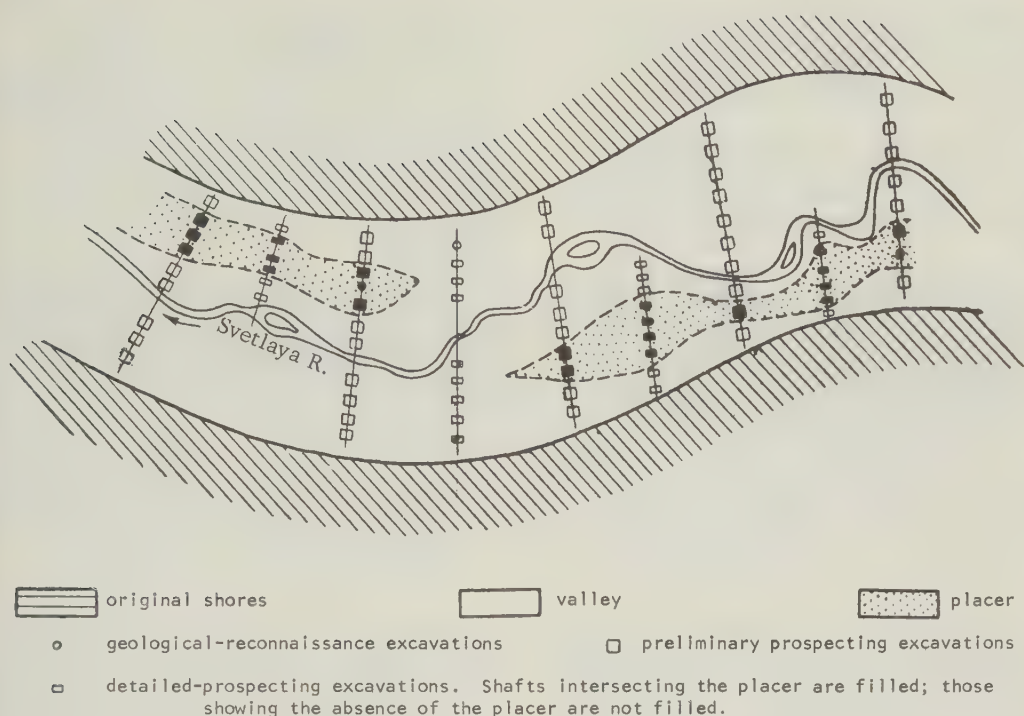


FIGURE 209. Scheme of prospecting a valley placer deposit.

mineral, variable in width and thickness of bed and peat, and also having frequent interruptions in the bed along the trend of the valley. The bed is divided only according to test data. The grains of valuable mineral are of varying degrees of roundedness; grains of large size and native metal predominate. The bed of the placer is uneven, with steep dip, frequent pockets, depressions and sink holes. This group also includes placers, normally uniform in distribution of valuable mineral but having variable thickness and being highly stony. Typical of the third group are placers of small springs, small valleys and also some diluvial, and even eluvial, deposits.

Examples of spacings between lines and between shafts or borings in prospecting different groups of placer deposits are presented in Table 25.

Prospecting lakeshore and seashore deposits is done by lines of shafts or of borings normal to the shore line with distances between the lines and between the shafts approximately the same as for prospecting river deposits of the second group.

Prospecting of ancient deposits require fuller geological investigations. I. S. Rozhkov (1948) believes that prospecting them should be pre-

TABLE 25. Examples of distances between lines and between shafts or borings in prospecting placer deposits.

| Group of placers | Breadth of placer in meters | Distance for the category in meters | | | | | |
|------------------|-----------------------------|-------------------------------------|----------------|---------------|----------------|---------------|----------------|
| | | A ₂ | | B | | C | |
| | | between lines | between shafts | between lines | between shafts | between lines | between shafts |
| I | 60-120 | 200 | 10 | 200 | 20 | 400 | 20 |
| | 120-240 | 200 | 20 | 400 | 20 | 800 | 20 |
| | over 240 | 400 | 20 | 400 | 40 | 800 | 40 |
| II | under 60 | 50 | 10 | 100 | 10 | 200 | 10 |
| | 60-120 | 100 | 10 | 200 | 10 | 400 | 10 |
| | 120-240 | 200 | 10 | 200 | 20 | 400 | 20 |
| | over 240 | 200 | 20 | 400 | 20 | 400 | 40 |
| III | under 60 | - | - | 50 | 10 | 100 | 10 |
| | 60-120 | 50 | 10 | 100 | 10 | 200 | 10 |
| | over 120 | 100 | 10 | 200 | 10 | 200 | 20 |

ceded and accompanied by the making of detailed maps showing the distribution of productive horizons and their relation to particular sediments of continental formations.

Such operations carried out in regions of placer development in the Urals have shown that the Jurassic and Mid-Pleistocene sediments form the most productive deposits in this region.

Important in determining the age of loose sediments and in correlating cross sections are spore and dust analysis, study of the mineral remains of flora and fauna, study of the mineralogical and chemical composition of

panned samples as well as the study of the composition of valuable minerals. No less important is the study of the geomorphology, which is realized most simply from aerial photographs. In addition to the geological and geomorphological study of the region, lines of excavations should be made for studying the structure of ancient valleys (structural lines). Lines are dug across the trend of the valley to obtain full intersection.

Ancient placer deposits are in some cases more variable in structure and distribution of valuable minerals than contemporary deposits and they are therefore prospected on a closer pattern.

METASEDIMENTARY URANIUM DEPOSITS IN PRECAMBRIAN MARBLES AND CONTACT-METAMORPHIC ZONES¹

by

T.V. Bilibina, Yu.V. Bogdanov and I.S. Ozhinskii

• translated by Mark Burgunker •

ABSTRACT

The present paper is a discussion of some aspects of the geology of the uranium deposits in lower Proterozoic carbonates of one district. The inference that uranium, phosphorus and organic matter in the carbonates is of primary sedimentary origin comes from the fact that the uranium minerals are concentrated in only one stratigraphic zone of the thick lower Proterozoic sequence, that the uraninite is always intimately associated with apatite and graphitic matter, and that the greatest degree of uranium enrichment is encountered in intensely faulted zones. This type of uranium mineralization, apparently, is the result of the deposition, diagenesis, and subsequent metamorphism of the uranium-bearing sediments. Subsequently, regional metamorphism and folding created beds and lenses of uranium-bearing dolomitic marbles; the metamorphic processes also involved a redistribution and partial migration of the material in the rocks. A redistribution of uranium, and its concentration in favorable structural zones, was produced by the tectonic stresses associated with folding and shearing in the lower Proterozoic rocks. -- J. K. Hartsock

* * *

The problem of the origin of metasedimentary ores of Precambrian and Paleozoic Ages, including uranium ores, has been discussed repeatedly in the literature during the last several years (Domarev, 1956; Getseva, 1957, etc).

The present paper is a discussion of some aspects of the geology of the uranium deposits in lower Proterozoic carbonates of one district, taken as an example. The carbonates (limestone, dolomite and calcitic marble) alternate with amphibolite, sillimanite-graphite and other slates; these rocks originated as sedimentary-volcanic deposits in a geosynclinal environment.

Intensive tectonic activity which gave rise to more or less symmetrical folds, fracturing along bedding planes, and local zones of fragmentation is a characteristic feature of the history of the uranium-bearing beds. The metamorphism of rocks with various compositions and densities was related to the tectonic activity in a regular and intimate manner.

The uranium-bearing carbonates, together with the other Proterozoic metasediments, constitute a great anticlinal structure within the limits of which ore bodies are intensely faulted.

The tectonic deformation involved fracturing along bedding planes, which was superimposed upon flexures and plications; this type of deformation

finds especially strong expression at the contacts between carbonates and more elastic hornblende slates; drag folds are characteristics of the latter. The greatest concentrations of uranium ores are localized where tectonic strain was greatest; these strains take the form of narrow disharmonic folds and boudinage. We observed, as did O. S. Sukhanov and V. P. Kikul, that fragmentation into small blocks which are oriented along the strike of the local structure is characteristic of the inner portions of such folds; these blocks, however, are wedged-shaped if the fold is sinuous in plan. The blocks in folded calcitic (white) marble are generally made up of dolomitic - calcitic marble or contact-metamorphic rock.

The uranium bodies are encountered in dolomitic and calcitic marbles and limestones; they occur very rarely in contact-metamorphic rocks, graphites, and andalusite and other slates.

SHORT DESCRIPTION OF THE URANIUM-BEARING BEDS

The uranium-bearing carbonates are encountered in all stages of metamorphism, from weakly metamorphosed limestones to contact-metamorphic bodies, which D. S. Korzhinsky (1953) treated as metasomatic reaction products.

The uranium-bearing limestones and marbles are gray or black; they exhibit bedded structure and, in some cases, are massive. The banding, which is consequent upon alternations of beds or lenses of dense limestone and coarse-grained calcite, is especially striking. The texture of these rocks varies from one consequent upon fragmental patterns in the weakly metamorphosed varieties to granoblastic and hetero-

¹Translated from *Ob uranovom orudenении osadochno-metamorficheskogo tipa v dokembriyskikh mramorakh i skarnopodobnykh porodakh*; *Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva*, Vtoraya Seriya, part 88, no. 4, 1959, p.372-373.

blastic in the marble. Dolomitic-calcitic and calcitic marbles may be distinguished with respect to mineralogy; the latter, however, are dominant.

The presence of an apatite component (this may attain a magnitude of 25 percent) and graphitic matter is characteristic of the limestones and marbles.

Apatite (actually fluorapatite, with $\alpha = 1.635$) exhibiting very weak double refraction forms distinctive lenticular and veined small-grain aggregates.

Crystalline apatite is almost nowhere encountered in these rocks. The graphitic substance is distributed irregularly through the rock; it occurs in isolated lenses, and the orientation of these in general is controlled by crystallization planes. Small blocks of limestone, in which calcite constitutes the cement, are frequently enriched with graphitic substance.

The contact-metamorphic rocks generally occur at the boundaries between the limestones and the amphibolites, and less frequently at boundaries between limestones and micaceous slates in zones where the tectonic strain is greatest. Isolated diopside crystals, strongly oriented aggregates of tremolite and phlogopite and similar aggregates of fine-grain apatite and graphitic matter are encountered in the transitional zones between the limestone and the contact metamorphic complexes.

These transitional rocks include metasomatic complexes with similar mineralogies; these complexes are encountered where the petrographic transition is gradual, and a step-by-step replacement of one mineral by another can be observed. More specifically, this group includes diopsides, diopside-plagioclases, diopside-phlogopite-amphiboles, tremolites and graphite-tremolites.

Tremolite, and phlogopite, and less commonly plagioclase, calcite, apatite and sphene occur as subordinate components in the diopsidic rocks. Large diopside grains, which are frequently recrystallized from smaller granoblast aggregates, are also characteristic of this type of rock; these grains are distributed along the original bedding surfaces of the limestones. The optical constants of the diopside are $\alpha = 43^\circ$, $2V = 54^\circ$ and $\alpha - \gamma = 0.029$.

Plagioclase (actually andesine and labradorite) replaces the diopside, divides it crystals, and penetrates the latter as veinlike aggregates of small granoblast grains.

The same kind of relationships exist between plagioclase, on the one hand, and phlogopite and tremolite on the other.

The emplacement of metasomatic alkalic plagioclase occurred on an especially large scale in the diopside-plagioclase; this produced plagioclase-dominant rocks which preserved the original diopside structure. Local enrichment by fine-grained apatite and (less commonly) sphene is also encountered.

The selective replacement of plagioclase by scapolite (meionite) is especially characteristic for rocks which contain plagioclase. The scapolite occurs as two types of pseudomorphs:

1) homogeneous pseudomorphs in which the boundaries and optic orientation of the mineral replaced is retained, and

2) large fragments which constitute aggregates which, in turn, exhibit a mosaic pattern associated with a network of fine fractures. The rock become scapolitic, for all practical purposes, when all of the plagioclase has been replaced; such rock contains only "fossil" diopside, apatite and sphene.

The diopside-phlogopite-amphibole rocks consist of tremolite (α between 19° and 20° , $2V = -84^\circ$ and $\alpha - \gamma$ between 0.022 and 0.023) and - less frequently - edenite ($\alpha = 20^\circ$, $2V$ between 80° and 82° and $\alpha - \gamma = 0.033$).

Phlogopite and clear mica occur at various portions of the contact-metamorphic zones. The tremolite and and graphite-tremolite rocks do not generally, contain accessory minerals; the significant variations here are in the proportions between the tremolite and the fine, dispersed, graphite which it contains. The distribution of crystallization planes and the lateral texture of the original rocks control the occurrences of micas and amphiboles, as well as the distribution of apatite and graphite aggregates.

The presence of thin mylonite layers and the deformation of individual grains bear witness to the occurrence of fragmentation in the limestones and the contact-metamorphic zones.

The fragmentation produced quartz, calcite and in a very few cases, sericite; these minerals are encountered as metasomatic intergrowths. More intense fragmentation produced metasomatic quartz-calcite lenses with pyrrhotite and pyrrhotitic inclusions. Tongue-like bodies of pentlandite are frequently associated with the pyrrhotite. Sphalerite, chalcopyrite and molybdenite occur less frequently. Isolated occurrences of crystalline orthite and xenotime are also encountered.

CHARACTERISTICS OF URANIUM MINERALIZATION IN CARBONATE ROCKS

Uranium mineralization in limestones, marbles, and contact-metamorphic zones

assumes the form of occurrences of small uraninite grains which stand in an intimate paragenetic relationship to apatite and, less frequently, graphite and graphitic matter.

The uraninite which occurs in marbles and limestone is especially common in graphitic beds with strongly expressed lenticular structure and dark coloration; here the mineral occurs in layers and irregular aggregates of fine-grained apatite; the distribution of these layers and aggregates, however, is controlled by the layering of the marbles (figs. 1 and 2).

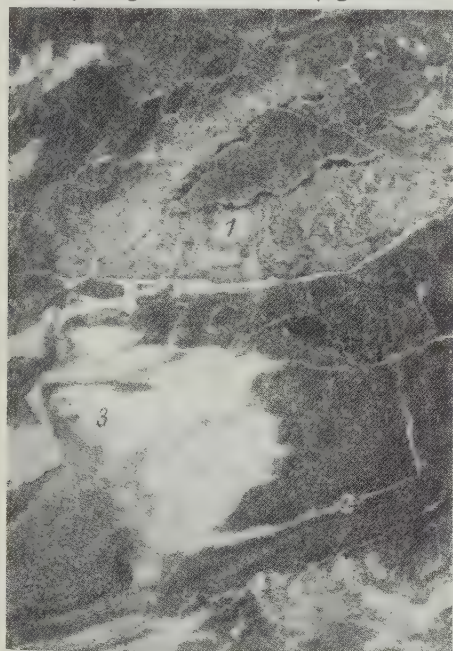


FIGURE 1. Amphibolitic uranium-bearing dolomitic marble.

Lenticular amphibole aggregate (1), bounded by flakes of apatite with uraninite and sulfides (2), white area calcite veinlet (3)

Uraninite and graphite are associated with "pressure umbrae" of dolomitic marble lenses where the last was enriched with apatite. The uraninite crystals have thicknesses between 0.001 and 0.01 mm, and are arranged along the boundaries between rounded apatite grains, in the spaces among such grains, and at intersections of metasomatic apatite veins. The uraninite particles which are embedded in apatite are generally surrounded by yellow aplochromic aureoles. The larger uraninite crystals, however, occur among the particles of graphitic matter (fig. 3). The crystals are cubic, but occasionally combinations of a cube and an octohedron or twins are encountered. Uraninite is embedded in calcite, amphibole or pyrrhotite only in the exceptional case.



FIGURE 2. X-ray photograph of dolomitic marble shown in Figure 1.

White area represents apatite and uraninite (1), intersection of apatite flakes and amphibole veinlets (2) may be noted.

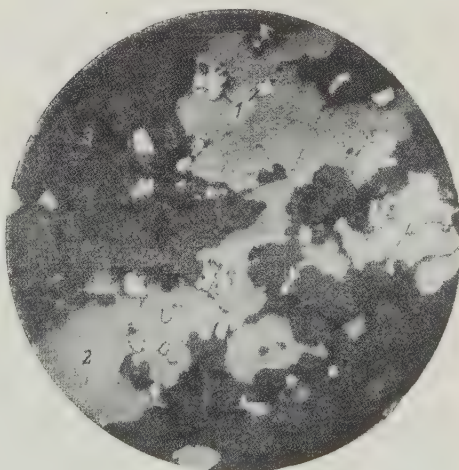


Figure 3. 1 - Euhedral uraninite inclusions; 2 - graphitic matter; 3 - dolomitic marble; 4 - pyrrhotite. (Polished surface; magnification 180 X)

Uraninite occurs as the same kind of small cubic grains, and only in intimate association with apatite, in metasomatic diopsides, diopside-

plagioclase and other rocks of the contact-metamorphic zone. The uraninite is most common in the diopside-plagioclase rocks; here it occurs in intra- and inter-formational crush zones.

Uraninite is generally embedded in diopside, plagioclase or apatite; the mineral occurs as in intergrowth with pyrrhotite, graphite and sphene less commonly. The mineral occurs, characteristically, in cleavage and fragmentation cracks, and as protruding angles of diopside crystals; the association with fine-grained apatite is an ever-present feature (fig. 4). The uraninite is surrounded by a uniform coating of chlorite alternates with fine flakes of clear mica in such cases (fig. 5). A yellow aplochromic aureole surrounds the uraninite grains in apatite.

The amphibole and the mica apparently crystallized after the uraninite, inasmuch as the last mineral is almost never embedded in either; there are cases, on the contrary, in which amphibole crystals, as it were, truncate the chlorite coating which surrounds the uraninite grains. Uraninite is present in micas only as part of fossil aggregates of fine-grained apatite.

The scapolitization of plagioclase, apparently, occurred after the uraninite and its chlorite coating had come into being; the fact that the microscope reveals corrosion of the coating by scapolite bears witness to this.

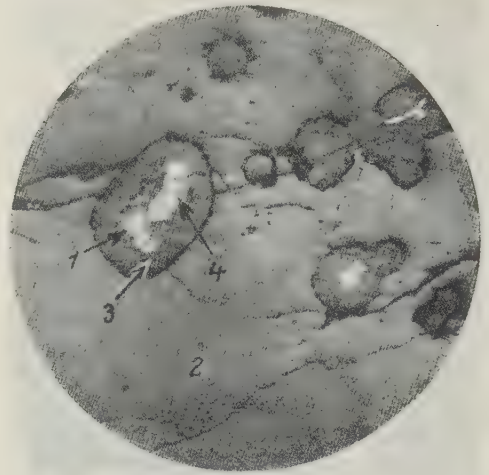


FIGURE 5. 1 - Uraninite inclusion; 2 - diopside; 3 - chlorite; 4 - pyrite. (Polished surface; magnification 180 X).



FIGURE 4. 1 - Looped apatite aggregates; 2 - uraninite in dolomitic marble; 3 - dolomite. (Transparent thin section, viewed without analyzer lens; magnification 180 X).

Uraninite occurs, in addition, in various slate sequences which constitute lenses in the limestones, and in porphyry bodies which cut the carbonates; the slates may be sillimanitic-graphitic or andalusitic. The uraninite occurrences characteristically are associated with boundaries and fissures between lenses.

Uraninite is encountered, further, in quartz-microcline bodies which have been injected into weakly migmatized sillimanite-graphite and andalusite; these injected bodies generally contain fine-grained apatite. The latter, together with the uraninite, forms veinlets which cut the injected bodies and the sillimanite porphyroblasts; the uraninite and apatite apparently are of later date. The uraninite, further, generally forms intergrowths with apatite along the boundaries between crystals of the latter mineral. Uraninite is always associated with apatite in the porphyry bodies which are cut by loops and irregular aggregates of the latter mineral; the orientation of the uraninite grains is controlled by random orientation of the apatite in such bodies, however.

Uraninite and apatite characteristically are absent from porphyry bodies which cut slate sequences.

METAMORPHISM IN THE ORE ZONES

The rocks of the ore zone here considered exhibit clear evidence of the regional metamorphism characteristic of amphibolite facies and, to some extent, sillimanite-garnet facies (Turner, 1951); this conclusion is drawn on the basis of the mineral assemblage and its structure. The intimate connection between the regional metamorphism and tectonic deformation, in this case, is characteristic; the latter involves differential movement, plastic deformations of variable intensities, and variable degrees of metamorphism.

The mineral assemblage in the amphibolitic slates and amphibolites is so typical of the latter that no special description is required.

The micaceous slates had their origin as arenaceous-argillaceous sediments and, generally speaking, constitute a sillimanite-garnet subfacies; these rocks, however, were produced by somewhat less intense metamorphism.

The mineral assemblage in the metamorphic limestones and dolomites is very uniform. The most common minerals in the assemblage are diopside, andesine-labradorite, the amphiboles (tremolite and occasional endenite [?]), calcite and phlogopite. Apatite, sphene and graphitic matter are always present. Scapolite, quartz and sulfide minerals also occur at isolated points.

The metasomatic minerals in the contact-

metamorphic zones are silicates and aluminum-silicates of calcium and magnesium, and to a lesser extent, calcium phosphates and titanates; these minerals constitute a characteristic assemblage produced by metasomatic replacement in carbonate and silicate rocks.

The presence of micas, however, constitutes a unique feature. The metasomatic replacement and crystallization of the minerals apparently occurred in a system which was essentially conservative, and the supply of new material was not an important factor. One may assume, also, that the mechanical stresses which acted in the rock controlled the intensity of the exchange reaction. Similar metamorphic effects in carbonates are quite common in areas where regional metamorphism has occurred; such rocks, in a word, are not exceptional (e. g., Harker, 1939).

The degree of metamorphism is not a decisive factor for the uraninite in the carbonates. This mineral occurs in the same form in both weakly metamorphosed limestones and contact-metamorphic zones. The paragenetic association of uraninite with apatite and graphitic matter is the only definite relationship involved here; this association is most intimate where tectonic fragmentation has been most intense. The position of uraninite in the crystallization sequence for the diopside-plagioclase series depends upon the relationships between this and later minerals (the amphiboles, phlogopite, and scapolite); the fact that this relationship controls the position of uraninite in the crystallization sequence bears witness to the closed structure of the system and the fact that the metamorphism involves only the elements and compounds in the original rocks.

The large amounts of graphite in the carbonate rocks is consequent upon a recrystallization of the organic matter present in the Proterozoic sediments. The results of studies carried out by F. Ya. Saprykin confirm the presence of organic matter in the uranium-bearing dolomites, and show that the concentration of the "C" hydrocarbons is 0.172 percent when the concentration of metal carbonates is 74.15 percent.

ORIGINS OF URANIUM MINERALIZATION IN MARBLES AND CONTACT METAMORPHIC ZONES

The inference that the uranium, phosphorus and organic matter in the carbonates is of primary sedimentary origin comes from the fact that the uranium minerals are concentrated in only one stratigraphic zone of the thick lower Proterozoic sequence, that the uraninite is always associated intimately with apatite and graphitic matter, and that the greatest degree of uranium enrichment is encountered in intensely faulted zones.

This type of uranium mineralization, apparently, is the result of the deposition, diagenesis, and subsequent metamorphism of the uranium-bearing sediments.

A study of the processes which the metamorphism of the ore zone involved, and the dominant and accessory mineral assemblages, points to the conclusion that the uranium-bearing sediments initially were carbonate muds which contained calcium phosphate and organic matter, which, in turn, took up uranium and other elements out of solution. The uranium, presumably, was precipitated out of solution as pitchblende; a reducing environment would have prevailed in the muds, because of the presence of carbonaceous matter and hydrogen sulfide. The presence of sulfides of iron, copper, zinc, nickel, cobalt and, to a minor extent, lead indicate the presence of hydrogen sulfide; part of the lead in the sediments, of course, was produced by radioactive decay. Subsequently, regional metamorphism and folding created beds and lenses of uranium-bearing dolomitic marbles; the metamorphic processes also involved a redistribution and partial migration of the material in the rocks. The layers and lenses of apatite, which are always associated with occurrences of graphitic matter, had their origin in the recrystallization of cryptocrystalline calcium phosphate; the organic matter in the muds constituted the source of the graphitic matter. The recrystallization of cryptocrystalline calcium phosphate to apatite, and organic matter to graphite, involved the removal of initially sorbed substances from the recrystallized products; the uranium, which is encountered in the uraninite grains along the boundaries between apatite grains, was separated in this manner. The uranium then crystallized as oxide, and this probably occurred simultaneously with the conversion of calcium phosphates to apatite and carbonaceous matter.

A redistribution of uranium, and its concentration in favorable structural zones, was produced by the tectonic stresses associated

with folding and shearing in the lower Proterozoic rocks. Closed folds and thickenings at anticlinal crests constitute such favorable zones; these structures are typical of rocks in which shearing occurred. The erosion of Archean granites over long intervals of time could have served as the primary source of the uranium which was deposited in the initial carbonate sediments. The uranium in these granites, apparently, was in a readily soluble form, and was carried by rivers to a shelf-type sea, where it was precipitated chemically in a reducing environment.

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THE MAGNETIC PROPERTIES OF WOLFRAMITE GROUP MINERALS¹

by

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• translated by E. A. Alexandrov² •

ABSTRACT

The study of magnetic properties of members of the wolframite group indicates that they are paramagnetic minerals. Anisotropy of magnetic susceptibility is characterized by the presence of three principal directions. Two of these directions coincide with the crystallographic axis. The axis of easiest magnetization makes an angle of 8° to 13° with the edge (100), and accordingly displaces the axis of difficult magnetization. The intermediary axis coincides with L^2 of the crystal.

The presence of three different directions of magnetic susceptibility depends on the peculiarities of internal structure of wolframites. In particular it is caused by deformation of the polyhedron $[MO_6]$. Relatively small differences of X_L , X_Y and X_Z from each other (in predominantly ferrous varieties) indicate evidently a comparatively insignificant deformation of $[MO_6]$ octahedra within the structure. --Auth.

The minerals of the wolframite group form an isomorphous series, $MnWO_4$ (huebnerite) -- (Mn, Fe) WO_4 (Manganous-ferrowolframites) -- $FeWO_4$ (ferberite). The amount of MnO in huebnerites ranges from 23 to 25 weight percent; FeO in ferberites is on the order of 24 and (FeO + MnO) in wolframites is 23-25 weight percent [1]. Mg, Ca, and Sn are the principal admixtures (in parts of a percent) in wolframites. These admixtures have no substantial influence on magnetic properties of wolframites. The magnetic properties of wolframites depend mainly on the presence of Mn^{2+} and Fe^{2+} kations.

The determination of the static specific magnetic mass susceptibility (χ) was conducted in an electric apparatus operating by a pulsation method [2]. The precision of measurement is within 1 to 2 percent.

The measurements were performed on monocrystals (fragments with faces along cleavage planes) and powders prepared from monocrystals and from fine-grained aggregates. Mineral inclusions were removed from the samples. The samples were checked for ferromagnetic impurities. The crystals were oriented along crystallographic directions by means of a single circle goniometer. The crystals were then oriented in the magnetic field so that the direction of the magnetic lines of force was parallel to the Z-axis of the crystal (X_Z) parallel to the Y-axis (X_Y) and perpendicular to the edge (100) (X_L).

It was established that axis of the easiest

magnetization (X_L) makes an angle of 8° to 13° with the direction perpendicular to (100).

As it is very difficult to orient crystals along the axis of the easiest magnetization in the limited space of a self-induction coil, the author made only one observation. In other crystals the susceptibility was determined in the direction perpendicular to (100). The difference between these measurements [1, 2], judging from one measurement, is evidently not considerable. Results of the measurements are shown in Table 1.

Data of Table 1 indicate that minerals of the wolframite group are magnetically anisotropic. There are three directions of magnetic susceptibility coinciding approximately with the crystallographic axes X, Y, Z. The value of X_L for different, predominantly ferrous wolframites varies from 38.2 to 45.0. For predominantly manganous varieties these values are between 39 and 43.5. The value of X_Y varies between 31.4 and 36.4, and 35.7 and 39.5, respectively. The numerical value of anisotropy ($\Delta\chi = X_L - X_Y$) varies in the samples depending on the amount of Mn and Fe, within the limits 6.8 to 8.1, 1.8 to 5.0. The ratio $\frac{X_L}{X_Y}$ for ferrous varieties is about 1.2, while for manganous varieties it varies from 1.04 to 1.1. The value of the average specific magnetic susceptibility (χ), as measured on powdered samples, varies from 37.9 to 41.0.

Wolframite crystallizes in the prismatic class of the monoclinic system. The crystalline structure of wolframites has not been sufficiently studied. Only the locations of metal atoms have been accurately determined, while the loci occupied by oxygen atoms are only generally known. The monoclinic elementary cell contains $M_2[WO_4]$. The complex anions $[WO_4]^{2-}$ represent flattened tetrahedra, and the kations Fe^{2+} and Mn^{2+} are located inside the deformed octahedra [3, 4].

¹Translated from Magnitnye svoystva mineralov gruppy volframita: Nauchnye Doklady Vyshey Shkoly, Geologo-Geograficheskie Nauki, n. 2, 1959, pp. 62-65.

²Columbia University.

Table 1.

| Number of sample | Name of mineral | $\chi \cdot 10^{-6}$ | | | | $\chi \cdot 10^{-6}$ | $\Delta\chi \cdot 10^{-6}$ | χ_z/χ_y | Remarks |
|------------------|-----------------|----------------------|----------------|----------------|----------------|----------------------|----------------------------|-----------------|---------|
| | | $\parallel Z$ | $\parallel Y$ | $\perp (100)$ | χ_x^1 | | | | |
| 1 | Fe - Wolframite | 38.4 \pm 0.8 | 36.4 \pm 0.7 | 44.5 \pm 0.9 | | 39.1 \pm 0.8 | 8.1 | 1.2 | Fe>Mn |
| 2 | Fe - Wolframite | 38.5 \pm 0.8 | 36.9 \pm 0.7 | 45.0 \pm 0.9 | 46.2 \pm 0.9 | 40.2 \pm 0.8 | 8.1 | 1.2 | Fe>Mn |
| 3 | Fe - Wolframite | 35.4 \pm 0.7 | 31.4 \pm 0.6 | 38.2 \pm 0.8 | | | 6.8 | 1.2 | Fe>Mn |
| 4 | Fe - Wolframite | | | | | 39.5 \pm 0.8 | | | Fe>Mn |
| 5 | Fe - Wolframite | | | | | 37.9 \pm 0.8 | | | Fe>Mn |
| 6 | Mn - Wolframite | 39.6 \pm 0.8 | 38.5 \pm 0.8 | 43.5 \pm 0.9 | | 40.6 \pm 0.8 | 5.0 | 1.1 | Mn>Fe |
| 7 | Mn - Wolframite | 36.7 \pm 0.7 | 35.7 \pm 0.7 | 39.8 \pm 0.8 | | | 4.1 | 1.1 | Mn>Fe |
| 8 | Mn - Wolframite | 38.5 \pm 0.8 | 37.1 \pm 0.7 | 41.3 \pm 0.8 | | | 4.2 | 1.1 | Mn>Fe |
| 9 | Huebnerite | 39.5 \pm 0.8 | 39.5 \pm 0.8 | 41.3 \pm 0.8 | | 41.0 \pm 0.8 | 1.8 | 1.04 | Mn>>Fe |
| 10 | Huebnerite | 38.3 \pm 0.8 | 37.0 \pm 0.7 | 39.6 \pm 0.8 | | | 2.6 | 1.07 | Mn>>Fe |
| 11 | Huebnerite | 38.3 \pm 0.8 | 37.6 \pm 0.8 | 39.7 \pm 0.8 | | | 2.1 | 1.06 | Mn>>Fe |
| 12 | Huebnerite | | | | | 40.5 \pm 0.8 | | | Mn>>Fe |
| 13 | Huebnerite | | | | | 40.7 \pm 0.8 | | | Mn>>Fe |

Sample 1. -Bayevka, Urals; 2, 4 - Neudorf, Harz Mtns.; 3 - Zinnwald, Bohemia; 5 - Nederland, Boulder, Colorado; 9, 10, 11 - Dzhdida, Buryat - Mongolia; 6, 7, 8, 12, and 13 - locations unknown.

As previously indicated, the magnetic properties of wolframites depend on the presence of Fe^{2+} and Mn^{2+} . The free Fe^{2+} ion is in $5D_4$ state. It is known [5] that the orbital moments of a series of ions including Fe^{2+} , which compose part of the crystal lattice are "frozen" by the influence of the asymmetric electric field of the surrounding ions. To determine the factors influencing the magnetic properties of the Fe^{2+} in wolframites, it is necessary to determine their effective magnetic moments (P_{eff}). The latter are determined according to a formula: $P_{eff}^2 = \frac{3kTM}{N\beta^2}$ where k is Boltzmann's constant.

T - Temperature in $^{\circ}K$
M - Molecular weight
N - Avogadro number
 β - Bohr magneton

Average values of P_{eff}^2 for predominantly ferrous and manganous varieties of wolframites are shown in Table 2.

Table 2.

| Ion | Average value of χ for Fe^{2+} and Mn^{2+} varieties 10^{-6} | Theoretical P_{eff}^2 for free ion P_T | Experimental P_{eff}^2 according to literature for Fe^{2+} and Mn^{2+} in solid salts P_{lit} [5] | Experimental P_{eff}^2 for Fe^{2+} and Mn^{2+} in varieties of Wolframites P_e | Theoretical P_{eff}^2 under conditions of "frozen" orbital moment P_{ts} |
|-----------|---|--|---|--|--|
| Fe^{2+} | 39.2 \pm 0.8 | 45 | 25 - 30.2 | 27.9 | 24 |
| Mn^{2+} | 40.7 \pm 0.8 | 35 | 34.2 | 28.9 | 35 |

Since the wolframites Fe^{2+} and Mn^{2+} are present simultaneously, P calculated according to formula (1) is higher for Fe^{2+} and lower than Mn^{2+} . The latter values, as shown in the table

on the average are equal to 27.9 for Fe^{2+} , and 28.9 for Mn. The intermediate value P_e , between P^2 and P_{st}^2 indicates that the orbital magnetic moments of $3d^6$ electrons of Fe^{2+} influence the magnetic properties of wolframites only to a certain degree.

The density of the cloud of d electrons of Fe^{2+} , which bring about the bond with $[WO_4]$ groups, is evidently concentrated predominantly along the direction of forces of the easiest magnetization. The density is lower in two other directions and is caused by the electronic polarization by oxygen. Fe^{2+} is coordinated by six oxygen atoms, but the form of the coordination polyhedron is a threefold deformed octahedron. Peculiarities of the configuration of the coordination polyhedron $[MO_6]$, and consequently, the distribution of the Fe^{2+} electron cloud density explain the observed anisotropy in wolframites.

Free Mn^{2+} ion is in $6S_{5/2}$ state. Its magnetic properties are determined exclusively by

the spin magnetic moments of electrons. Effective experimental magnetic moments for predominantly manganous varieties of wolframites have an average value of 28.9

The distribution of electron density for the S state is characterized by spherical symmetry. Therefore, the Mn^{2+} electron cloud has no noticeable polarization induced by oxygen. This fact indicates that pure manganous wolframites (huebnerites) can be practically considered as magnetically isotropic. The presence of Fe^{2+} , together with Mn^{2+} , increases their anisotropy [1].

[Ed.: The last two paragraphs of the original constitute the abstract for this translation].

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THE STUDY OF FACIES: BASIC PRINCIPLES¹

by

D. V. Nalivkin

• translated by Peter A. Florek •

EDITOR'S NOTE

D. V. Nalivkin's two-volume work, *Study of Facies*, 1956, was initially chosen for publication in full under the translation program of the American Geological Institute. Reviewers of the nearly completed translation, however, have since recommended against publishing the work in its complete form. Instead, a review of the work's salient points will be prepared for early publication in *International Geology Review*, and in addition, the following portion of the translation has been selected for separate publication.

Details of how, and in what form, copies of the remaining parts of the translated work may be obtained will be announced when the review has been published and interest in the work is better known. --M. R.

ABSTRACT

The concept of facies is attributed to the Swiss geologist, Gressly. It is definable in terms of a uniform portion of a land surface or sea floor, with definite implications of geography. Different facies in the Black Sea and Caucasus are cited. Gross uniformity of lithology and biocoenose are implied within facies. The work of numerous Russian and American geologists in facies studies is reviewed. A classification of facies is proposed in which the concept of *servia* and *nimia* is introduced. --M. Russell

INTRODUCTION

The "facies" concept appeared in geology more than a hundred years ago. In 1838, the Swiss geologist, Gressly, wrote:

"I have come to the conclusion that every deposit reveals rather specific variations within the limits of its horizontal extent; these variations represent individual uniformities as much in lithologic make-up as in their paleontologic fossil records, and are governed by determinable and invariable laws."

For these changes, Gressly suggested the name, "depositional facies".

We consequently see that the basic reason for the introduction of the "facies" concept was the fact that deposits of the same age are of a distinct form and this form varies at differing points on the surface of the earth.

The main attainments in facies study, however, were won comparatively recently, and are attributable to the increasing influx of the paleogeographic method into geologic research.

Facies analysis is a natural development in paleogeographic science, which has as its objective the restoration of the distribution of the seas and the land, recreating of the terrestrial environment and all aspects of the earth's surface as they were in past geologic epochs.

Facies study in large part asserts itself as the study of the conditions of formation of sediments. Associated with sediments -- sedimentary deposition -- are an infinite number of often sizable occurrences of important metaliferous and non-metallic minerals. It is sufficient to only mention the coal measures of the Kuznetsk Basin and the Donetz Basin, the Baku and Grozny oil fields, the Solikamsk potash deposits, the iron ores of the Kerch Peninsula and of the Lipetsk district, the copper-bearing sandstones of the Urals and Kazakhstan, the bauxites of the Tikhvin and Ural regions, in order to make clear the tremendous economic importance of mineral deposits associated with sedimentary strata.

A knowledge of the conditions of formation of these sedimentary thicknesses is a knowledge of the conditions of formation of the mineral occurrences associated with them.

The conditions of formation of mineral regions are consequently the foundation, the bedrock, on which one must build all study of a given mineral occurrence, and in particular its prospect. An understanding of the peculiarities of a specific basin in which a given

¹Translated from *Obshchiye ponyatiya*, chapter 1, p. 5-15, in: *Ucheniye o Fatsiyakh: Geograficheskiye usloviya obrazovaniya osadkov* [Study of Facies: Geographic conditions of formation of sediments], v. 1 (of 2), Akademiya Nauk SSSR, Otdelenie geologo-geograficheskikh nauk, Moskva-Leningrad, 1956.

mineral deposit was formed, often defines the boundaries of the deposit and determines its nature and capacity; that is, basic material is given not only for purely geologic investigations but also for work involving the evaluation and development of mineral properties.

Each prospector working in regions of sedimentary mineral occurrences must be aware of the conditions of their formation, must be acquainted with those facies with which they are associated and must be skilled in their interpretation. He otherwise would be conducting his work in a rather inefficient and purely mechanical manner.

Of no less significance is facies analysis for the geologist, whose main task is the establishing of stratigraphic cross-sections and the determining of depositional sequences of sedimentary strata. As a prerequisite to this, he must understand the conditions of formation of sedimentary deposits. He must have an adequate background in facies study. Facies study is still more useful in the resolving of another very important problem, namely, the problem of the areal distribution and boundaries of a given sedimentary accumulation.

The study of facies is also of great importance to the paleontologist. On the character of a sedimentary deposit and the conditions of its formation, depends the development and distribution of its plant and animal world. The study of facies enables the paleontologist to reconstruct the physicogeographic conditions of the past, and these conditions, in turn, have operated as the main elements controlling the development, the distribution and characteristics of animal forms. And conversely, peculiarities in structure of the remains of fossil animal and plant organisms enables us to judge the conditions of formation of those sediments in which they are preserved.

THE FACIES CONCEPT

As evident from Gressly's original definition, facies indicates a sediment or sedimentary rock which in its extent possesses identical lithologic composition and encloses identical fauna and flora. The definition is as applicable to consolidated sediments which often have undergone further alteration, as it is applicable to contemporary unconsolidated sediments.

An assemblage of animals and plants associated with a given facies is termed a biocoenose. the aggregate of physiogeographic conditions associated with a given facies is a biotope.

The fundamental purpose of the science of sedimentary petrology is the study of sedimentary rocks. Facies study, however, is of much broader scope than are the narrow limits

of petrology. In the study of facies, petrology serves as only an aid to learning, although we must concede that it contributes immensely important factual material.

Facies study is primarily committed to the descriptive restoration of the paleogeography of ancient environments. This objective of facies study has stimulated the great interest and importance which it has obtained in recent times.

In the study of the fossil organism, we examine its skeletal form in order to discern those elements that are characteristic of species. On the basis of these elements, we reconstruct the entire organism with the aggregate of its soft parts which in most cases have been long non-existent. Precisely these same methods are used in facies study. We examine features of a rock that are responses to a sector of energetic natural processes with characteristic climate, physicogeographic conditions and organic life.

It would be an indication of professional inadequacy if the paleontologist were to merely describe a faunal skeletal form and made no attempt to reestablish the characteristics of the entire animal, including its peculiarities, interrelationships and even the conditions of its life.

In similar circumstances is the geologist who undertakes a study of sedimentary strata and does not attempt a descriptive reconstruction of the peculiarities and interrelationships of that portion of the earth's crust on which they were deposited.

An accurate and methodical study of sedimentary structures requires that the geologist must be able to perceive the many implications inherent in a section of land or sea floor with its organic population and physicogeographic affinities.

"Facies" is not equivalent in meaning to "sedimentary rocks"; that is, it is not a strictly lithologic term, but is definable as a uniform portion of land surface or sea floor. Accordingly, the full connotation applied to the concept includes geographic or paleogeographic implications.

Neither can we consider the concepts of facies, biocoenose and biotope as synonymous, but facies do include in themselves, the biocoenose, the biotope and sedimentary rocks.

Some facies have existed in the past, or exist now, within which no sedimentary material had either formerly been deposited, or in which no sedimentary material now remains. Examples are the crests of mountains and generally speaking, all eroded regions. However, there can be no deposited sediment that

can be thought of as external of some kind of facies.

Facies are units of topography. All sedimentary material of the globe is subdivided into facies. The facies is as much a basic unit of the paleogeographic system of nomenclature as species is a basic unit in the biologic sciences. All sedimentary material of the earth, whether marine or terrestrial in origin, is subdivided into facies in the same manner as the species subdivision is applicable to organic forms in zoology.

To illustrate this, we will consider the Black Sea, consisting of the following facies: At the shore are facies of sea-cliff detritus, sand facies, and pebble-conglomerate facies. Farther from shore, sand facies intergrade into silt facies. Finally, at depths of over 200 meters, silt facies predominate. These complexes of facies are subdivided into lesser units; for example, the several silt facies distinguishable at depths of 60 to 200 meters are subdivided into facies of phaeophytes silt, miliolid silt and terebratulid silt. Their names have been derived from the names of their characteristic organic populations.

The Caucasus range is a second example. At the summits are facies of glacier deposits, eluvium and glacial-lake sediments. On the slopes, are facies of fluvial deposits, boulder conglomerates, outwash and avalanche facies. Finally, at the foothills, are facies of alluvial fans, stream channel deposits, eolian sands and loess.

The increasing attention given to the facies concept in contemporary geologic literature is accompanied by a great diversity in its interpretation. In some cases, this has been reflected by an excessively generalized usage of the term, such as "facies of carbonaceous deposits", "delta facies", "desert facies", and similar nonspecific terminologies. Such broad interpretation can only lead to confusion and ambiguity.

Similarity of form -- this is the basic property of facies, precisely in the manner in which similarity of form is the basis of species taxonomy in the biological sciences. This is a point that was strongly emphasized in Gressly's definition of facies.

Overgeneralized interpretations of the facies classification are contrary to this basic principle of similarity. Carbonaceous deposits, for example, include the facies of alluvial, lacustrine and paludal deposits. The delta is even more diverse in its make-up, and includes facies of river beds, floodplains, abandoned stream channels, fresh water lakes, brackish lakes, lagoon, beach deposits, eolian sands and a great number of others. For deposits of

such a complicated and heterogeneous nature, it is necessary to employ either a proposed complexity of individual names, or a rather simpler "complex of facies", or a still more simplified "facies" concept.

It would accordingly be acceptable to speak of a "complex of delta facies", or "deltaic facies", but the use of the very indefinite term of "delta facies" would be a grave error.

In determining the boundaries of whatever facies we might wish to consider, it is first necessary to look for gross uniformity in lithologic composition and in biocoenose.

Relatively rare, but nevertheless encountered are errors of the other extreme, in which an infinitesimal lithologic subdivision is indicated as a facies, such as an extreme differentiation of limestones. Such differentiations, of course, are important, but regardless of this, these subdivisions would not be facies, but would only be their variations, in much the same way as there is the subdividing of species in the organic world.

In her monograph, M. B. Klenova (1948) reflects on the nature of the term, "marine facies". She points out the same conditions which were advanced by myself in the concept, "contemporaneous facies", and advanced by L. B. Pustovalov (1940) [1933 ?] in his concept of "geochemical facies", and cites the following definition:

"Marine facies should be called a portion of the sea bottom with the same physico-geographic conditions; a historical complex in the process of undersea geologic development which has identical flora and fauna. In order for facies to be validly equivalent, it is necessary that they should have undergone the same history."

Accordingly, silt facies in basins with subsiding floors cannot be equivalent to identical facies in basins with emergent floors.

The introduction of the "historical moment" as a feature of the facies concept, that is, the relating of facies development to tectonic movements, is of the utmost importance. In the analysis of facies data, this is necessary as was already shown by myself, (Nalivkin, 1932) and frequently shown to be true in actual practice.

But in the nomenclature of individual facies, the historical moment has not been generally included. We do not distinguish "argillaceous facies of regressing seas" from "argillaceous facies of transgressing seas". This may well be an oversight which should be cleared up, but more likely the distinction between these facies is so minute and difficulty perceptible that there is no need for such a formalized distinction in nomenclature. In the articles of M. B. Klenova, such refined nomenclature also did not obtain

attention.

Facies study has attracted the energetic attention of Soviet geologists. Contributions to facies literature by N. B. Vassoyevich, B. P. Markovsky and V. A. Zhemchuzhnikova were published in "Litologichesky Sbornik", (1948) [collected works on Lithology].

In the United States, an analogous collection was published a year later, (Sedimentary Facies in Geologic History, 1949, [G. S. A., Memoir 39] translated into Russian in 1954).

The North American literature appears to lack evidence of the systematization of facies study which has been developed in this country [U. S. S. R.]. For example, in one of the leading articles of the collection, by the prominent American stratigrapher, Raymond Moore (Moore, 1949), appears the somewhat obscure term, "lithofacies" which some months earlier was used by a second prominent geologist, (Krumbein, 1948, Krumbein and Sloss, 1951) as a designation for sedimentary facies.

Worthy of attention is the great work of Easter, (1934) on the Devonian facies in Pennsylvania. He introduces the element of duration in time. For facies that were deposited or deformed during the course of several epochs, he proposed the term, "magnafacies", for facies that occur entirely within the time boundaries of a single epoch, he suggested the term, "parvafacies".

As an example, the folded massif of reef-core limestones of the Urals which extend through the course of the upper Silurian, lower Devonian and the Eifelian stage, would be known as "magnafacies"; a section corresponding to a single stage such as the Eifelian, would be known as "parvafacies".

B. E. Khain (1950), in his interesting article, places just emphasis on the importance of the contributions to facies study by geologists in this country. He makes note of the fact that they not only have pointed out the impracticabilities of the tendency to view facies as merely rock specimens, but have also demonstrated the interdependence and response of facies to dynamic physicogeographic conditions. Most important, they have shed light on the tremendous importance of tectonic movements as determinants of the nature and history of facies formation.

B. E. Khain (1950) writes:

"It has become clear how much richer, meaningful and many-sided is the impressive panorama of the facies concept. Its omnipresence in paleogeography, lithology, geotectonics and geochemistry and ecology is an indication that it is, in the full sense of the word, a geologic

"concept". Facies -- this is one of geology's most fundamental of intellectual tools. Its use aids in the resolving of one of the main tasks confronting present-day geology, that of reconstructing the history of the earth."

All basic groups of facies are associated with tectonic movements. These are outlined below in a series of divisions.

Distribution and Boundaries of Facies

The areal extent of facies differs sharply. Some facies attain tremendous dimensions, such as the red clays in the Pacific Ocean which cover a larger area than the entire continent of North America. On the other hand, some localized oyster reefs are only some tens of square meters in area.

Any attempt to establish whatever regularity in the dimensional characteristics of specific types of facies would be rather difficult. One can only say that in the near-shore zones of the sea at depths of 40 to 60 meters, facies are the most diverse and occupy the smallest individual areas. At depths of from 60 to 400 meters, facies are larger in area and of lesser variety. Finally, at depths of below 2,000 or 3,000 meters, only a few facies are extant, but they are tremendous in size.

Terrestrial and lagoonal facies are also variable in their distribution. These, however, do not attain such enormous dimensions as do the facies of deep-sea sediments.

The vertical thickness of facies is also extremely variable. For some facies, it is a matter of hundreds of meters, and sometimes of kilometers. The tremendous vertical thicknesses of the Neocene conglomerates of Central Asia, the reef limestones of the Caucasus, or the Triassic dolomites of the Tyrol are examples. The vertical thickness of other facies measures only one or two centimeters, (such as a lamina of siliceous shales, or many glauconite-phosphorite facies).

The boundaries of facies also vary widely. Some facies gradually intergrade into others, such as marine sands which imperceptibly intergrade into silt. On the other hand, boundaries between facies may be sharp and abrupt, as would be the boundary between a bryozoa or a stromatoporoid reef and abutting clays and sands.

CLASSIFICATION OF FACIES

A. A. Borisyak (1935), one of the first to become aware of the interrelation of facies with their physicogeographic environment, subdivided

them into three large groups:

1. Marine facies
2. Lagoonal facies
3. Continental facies

This subdivision has become generally accepted. The term, "formations" was suggested for these groups, but has not been extensively used because "formation" had been already applied as a designation for several differing types of geologic phenomena.

There have been no systematized designations for other smaller groups of facies, for example, those occurring as delta, coral reef, fluvial or lacustrine deposits. At the same time, the need for such systematization has increased immeasurably. Such terms as "microfacies", "mezo-facies" and "macrofacies" as have appeared in some articles are both vague and ambiguous.

There is a need for a systematic classification of facies similar to that which has been adopted in the taxonomy of the organic world. In the biological sciences, as is well known, species is consolidated into genus, genus into family, family into class, class into phylum and phylum into kingdom. The working out of an analogous classification for facies presents many problems. The classification must be based both on paleogeographic criteria and on a graphic delineation of the physical characters inherent in sedimentary forms. The complexities and difficulties involved in a solution are obvious; but we are already committed to that end.

We begin with certain concrete examples. Oceans are subdivided into abyssal, bathyal and littoral regions. Literally, these are the ocean floor, the continental slope and the shelf.

The ocean floors are amazingly monotonous, but there are distinct regions of widespread distribution of a variety of such oozes as the globigerina, diatomaceous, pteropod, radiolarian and the red, deep-water clays.

The continental slope also tends to be rather monotonous. Generally, there is a distribution of a larger variety of sediments than on the ocean floor, but there are also areas within the slope where the predominating sediments are the oozes already mentioned. The greatest variety of facies in the region exists on the upper portions of the continental slope, in areas where strong currents are operative. Locally too, where large rivers empty into the sea, there is evidence of a large variety of facies, each with a distinctive character. Deposits of green glauconite silts and sands are also associated with these areas. The presence of deep submarine valleys is, similarly, conducive to the deposition of representative sediments. On the lower portions of the slope, where monotonous physico-geographic conditions prevail, the consequent sediments are, in like manner, of

only one type, the blue muds.

The shelf is the locale of the greatest variety of facies and their complexes. The character of deposition on the lower portions of the shelf is similar to that prevailing on the upper portions of the continental slope. Consequently, many facies complexes are of similar affinities, such as those along bottom irregularities where strong currents carry material in suspension, those in submarine valleys, those in proximity to the discharge of large rivers and regions of development of the blue muds.

The upper portion of the shelf has deposits which are often conditioned by the character of the detrital supply available from the coast regions of the continent. Distinctive types include the shelf of young folded mountains, as is the shelf adjacent to the Cordilleras and the Andes, the shelf of ancient massifs, such as the shelf along the coast of western Siberia and along the shores of Brazil, and the shelf of the coastal plain with widespread area but moderate heights. Younger developments are the shelf areas adjacent to abrupt limestone cliffs, typical of the eastern shore of the Adriatic Sea, and the shelf associated with desert regions, such as the shelf along the southwest coast of the Caspian Sea. Still less developed are the shelf areas of coral reefs, where carbonate deposition predominates, and shelf areas where rocky shores are washed by long-shore currents, such as the Puertaless Plateau region on the east coast of Florida.

All of the many types of shelf environments that have been mentioned are characteristic of the shelf areas of the open ocean where there is free circulation of marine waters. It is apparent that these would not exhaust all possible types of open-ocean shelf regions, but are only most typical of the largest number of locations.

A second complex of facies is associated with shelf regions of the insular seas, the landlocked or partially-landlocked arms of the ocean which extend into the land. Shelf deposition in these cases is conditioned either by strong inflowing currents, or by very little motion of completely isolated waters. Shelf deposition in the barred basins along the coasts of Denmark and Holland approximates the conditions of the second-mentioned, completely isolated waters. Estuaries are also typically of two types -- those with strong current flow and those without. Specific types of facies complexes are characteristic of the shelf areas of semi-protected large bodies of water such as the Baltic Sea and Labrador Bay, of smaller bays such as Sevastopol Bay, or of shelf areas associated with coral atolls.

We can see from the foregoing that the character of facies and their complexes differs in varying marine environments. On the shelf, we can often discern a four-part sequence such as the following:

- IV. Ocean
- III. Shelf of an insular sea
- II. Strait without current flow
- I. Silt deposit

The first category is a facies, its composition is uniform throughout.

The second category is a complex of facies. Silt deposition occurs in offshore areas of the strait, but nearer to shore, the silt grades into silty sand and in the surf zone, into pure sand.

The third category is a complex of facies complexes, since a shelf of an insular sea can include within its limits, not only straits without current flow, but also bays, lagoons, straits with strong currents, regions of deep shelf and others.

The fourth category is a group of complexes of facies complexes, a composite of its three preceding categories.

The second example is the coral atoll, for which the following sequence is applicable:

- IV. Ocean
- III. Coral atoll
- II. Seaward slope
- I. Surf-zone breccia

The first category is again of uniform composition and is a facies. The second is a complex of facies, since it includes not only the facies of surf-zone breccia, but also facies of surf-zone sands and others. The third is a complex of facies complexes, that is, a composite of facies complexes associated with various portions of the seaward slope, the above-water surface of the atoll and deposits in its lagoon.

The third example is a large river delta, which is an element of the lagoonal zone of deposition, and in turn is composed of fluvial, lacustrine, lagoon, terrestrial and marine deposits. Each of these named is a complex of facies and is composed of individual facies. For example, the fluvial deposits, those of the river valley, can be outlined in the following four-part sequence:

- IV. Lagoonal zone
- III. Delta
- II. River valley
- I. Crossbedded sands

The fourth example is the desert, an element of continental deposition. Its parts, in turn,

are playa lakes, dune sands, beds of intermittent streams, regions of plains detritus and others. Each of these complexes of facies is subdivided into several facies. Selecting for an example, one of these complexes of facies, the intermittent-stream bed, we can outline the following four-part sequences:

- IV. Continent
- III. Desert
- II. Dry stream bed
- I. Accumulation of angular pebbles

The fifth example is a large mountain range. This also is an element of continental deposition and is subdivided into complexes of facies such as those of deposition in river beds, glacial valleys, boulder zones, alluvial fans and areas of loess accumulation. The following sequence is applicable:

- IV. Continent
- III. Mountain range
- II. Glacial region
- I. Ground moraine

All of the examples so far cited were those of contemporary deposition. Sediments deposited during past geologic history can be similarly outlined. The graptolite shales of the Tien Shan range are examples. These are outlined in the following four-part sequence:

- IV. Marine deposition
- III. Deposits of restricted basins
- II. Graptolite shales
- I. Claystone member with graptolites

"Graptolite shales" is a common designation for a large complex of many different facies, some of which are argillaceous sandstones, argillaceous limestones, black bituminous shales and gray arenaceous shales.

The seventh example is the coal-bearing thickness. This is classified into the lagoonal zone of deposition, and is a complex of facies complexes which are subdivided into the facies complexes of swamp, river, terrestrial and marine sediments. Each of these facies complexes is an aggregate of several individual facies, for example, swamp deposits are composed of coal-bed facies, claystone facies and fine grained sandstone facies; river deposits of cross-bedded sandstone, argillaceous sandstone and small lenses of pure claystone.

The sequence of facies categories will be as follows:

- IV. Continent
- III. Delta of large river
- II. Swamp in delta environment
- I. Coal bed

The eighth and last example is the upper

Permian Tartarian series of the Volga River region, representing typical plains deposits and composed of complexes of facies of lacustrine and fluvial deposition. In other nearby districts, additional complexes of facies occur, such as the flat alluvial cones of redbeds in the Ural Mountain piedmont district; and individual facies, for example, the quicksands along the Northern Dvina river.

The following sequence is an example:

- IV. Continent
- III. Continental Plain
- II. Lake
- I. Portion of lake floor which is the site of accumulation of light colored, nodular limestones.

From the variety of examples shown, we can see that a four-part classification is adequate for all facies and their complexes. It can be adopted as fundamental, and is even more simple than the five-part classification consisting of species, genus, family, class, and phylum that is used in the classification of organic forms.

In the classification of sedimentary deposits, there are already names in common use for the first and the fourth categories -- "facies" for the first, and "formation" for the fourth category. The term, "formation" applied to "continental formations" is an example. Used in this sense, "formation" already has the connotation of a totality of many types of sediments with a variety of affinities. We can accordingly retain this already established usage, despite its concurrent use and different meaning in other fields of reference.

For the intermediate divisions, the second and third categories, I have proposed the names, "servia" and "nimia". Servia is interpreted as generally equivalent in meaning to "assemblage" or "cluster"; nimia to "supermeasured" or "supergraduated".

Servia

Servia is accordingly a complex of facies intergrading from one to the other, which are constituents of a single geographic phenomenon. These can be facies of lake, glacial valley, coral atoll lagoon, the beach environment, straits, sounds, and a wide variety of equivalent features. In fossil aspect, they represent fossil suites.

Gressly at an early date became aware of sedimentary strata as aggregates of many individual facies; in effect, serviae. His insight into these relationships was the main reason motivating him to introduce his basic facies segregations.

The servia differs from the facies in its heterogeneity of lithologic composition and organic population. Often, but not invariably, serviae are of greater vertical thickness and wider distribution. The most common error of geologic facies nomenclature is the confusion of serviae with facies.

Nimia

Nimia is a complex of serviae intergrading from one into the other and comprising large geographic regions. Complexes of serviae are the deltas of large rivers, such as the Volga or the Ganges; large seas such as the Baltic Sea or the Caspian Sea; mountain ranges as the Caucasus or the Tien Shan; deserts such as the Kara-Kum or the Sahara; continental shelf areas such as the shelf adjacent to the northern coast of Eurasia or the shelf along the western coast of North America.

Great size alone is not a distinguishing feature of nimiae, since some can be of smaller dimensions, for example a coral atoll which is composed of the serviae of the lagoon, the serviae of the above-water portion of the atoll surface, and serviae of the seaward slope.

In fossil aspect, the nimia includes fossil suites of more or less considerable magnitude. Examples of nimiae also include the carbonaceous strata of the Donetz Basin, the Neocene deposits of the Fergana Valley and the biohermal reef massifs of the lower Permian deposits of the Russian Platform.

The distinguishing of serviae from nimiae in fossil complex is often rather difficult. For example, the prolific fossil record of the Zechstein-stage strata with their widespread distribution would approximate the characteristic complexity of a nimia. However a careful analysis of facies data indicates that the deposits are only of servia magnitude. At the same time, the strata comprising the upper Permian Kazanian series which includes not only deposits of the Zechstein stage, but also carbonaceous suites, saline deposits and redbeds, are undoubtedly deposits that are of nimia complexity.

Formation

This is a complex of nimiae, the largest subdivision of global deposition. Three formations have customarily been recognized, the continental, lagoonal and marine. But it is by no means impractical to identify other formations, such as the geosynclinal formation, which includes all regions of deposition of marine, lagoonal zone and coastal-continental sediments in tremendous volume, within great subsiding elongate downfolds in the earth's crust. The great complexities of

sediments associated with large archipelagoes such as the Indonesian and West Indian archipelagoes, typical contemporary geosynclinal belts, are classed as a "geosynclinal formation." Other examples of formations include all contemporary continents and oceans along with the Mediterranean Sea in combination with its component seas, the Adriatic Sea, the Aegean Sea and the Black Sea.

The entire fossil record of the Urals geosyncline can serve as an example of the tremendous diversity of fossil forms and organic populations associated with formations.

The greatest significance of the facies classification system as has been here proposed, rests in its ability to systemize the description of very complex strata such as the redbed thicknesses of the Ural Mountains piedmont region. Systematic descriptions of intricate sediments and accurate inferences leading to an understanding of the conditions of formation of depositional patterns are remarkably simplified by the separating out of a single servia environment from adjacent structures. The description of a Tartarian series of whatever region, for example, requires the separating out of serviae representing deposition in brackish waters, alluvial fans and of lacustrine, fluvial, paludal and many other types of environments. A study of the upper portion of the lower Cretaceous deposits of the Russian Platform invariably includes serviae of straits with strongly developed currents, straits without currents, bays, islands, sandy beaches and clastic deposition along shore environments.

Some serviae are related to only one type of nimia, but the majority can be constituents of a number of nimiae, such as the servia of the tombolo or spit, which is characteristic of the nimiae of shelf of the open ocean, shelf of the insular sea, the lagoonal zone and others.

In the classification, "formation continent", reappearances of a particular servia within a variety of nimiae classifications is still more frequent. All six of the continent nimiae also contain the serviae of the fresh water lake, swamp, brackish lake, river valley, intermittent stream, volcano, dune area and karst-topography region.

The classification of facies can be represented in the following manner:

FORMATION-OCEAN

Nimiae

Shelf of the open ocean
Shelf of the insular sea
Lagoonal zone
Inland seas
Epeiric seas
Archipelago
Reef zone
Bathyal zone
Abyssal zone

FORMATION-CONTINENT

Nimiae

Delta
Coastal Plain
Desert
Piedmont
Mountain Range
Continental Plain

As a further example, we will consider the classification of the nimiae of the shelf of the open ocean, shelf of the insular sea and the lagoonal zone of deposition

FORMATION-OCEAN

Nimia: Shelf of the open ocean

Serviae

Shore environment of the rocky coast
Shore environment of the coastal plain
Submarine valley
Submerged ridge
Strait
Islet
Region of glacial-marine deposition
Region of eolian-beach deposition
Region of pseudo-abyssal deposition

Nimia: Shelf of an insular sea

Serviae

Bay
Inlet
Barred basin
Mangrove swamp
Submerged valley
Stagnant basin

Nimia: Lagoonal zone

Serviae

Lagoon
Estuary
Hypersaline lagoon and coastal lake
Longshore bar
Peat lagoon and mud flats
Algal lagoon and coastal lake
Ironsilicate lagoon and coastal lake
Tombolo or spit

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BASIC FEATURES OF THE PALEOZOIC STRUCTURE OF CENTRAL KAZAKHSTAN ¹

by

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• translated by Research International •

ABSTRACT

Within the Paleozoic massif of central Kazakhstan two zones can be distinguished: the Caledonian to the southwest, the west, and the north; and the Variscan zone to the east and the southeast. These two major zones differ in their middle and upper Paleozoic sections, their magmatic activity, and the nature of their tectonic disruptions.

* * *

GENERAL REMARKS

During the last 10 to 15 years, great success has been achieved in the study of the geologic structure of central Kazakhstan. The many geological surveys executed during this period were, naturally, accompanied by further work on the stratigraphy of the whole section and the study of tectonic and magmatic activity in many important regions. The extensive utilization of geophysical investigations, including aeromagnetic surveys, as well as local drilling, has permitted the determination of structural features of many regions which are covered by a thick mantle of Mesozoic and Cenozoic rock. These new data have been partly reflected in the depiction of the geologic structure of central Kazakhstan on the most recent geologic map of the U. S. S. R. on a scale of 1:2, 500, 000 [24].

Central Kazakhstan occupies a unique position among the Paleozoic fold structures of Eurasia. It is located in the middle of the Ural-Sayan Paleozoic geosynclinal region equidistant from the bordering Precambrian platforms. It is separated from the Russian platform by the southern Urals and a belt of Paleozoic folds which form the base of the Turgay trough. It is separated from the Siberian platform by complex fold structures of Sayan, Kuznetsk Alatau, Gornaya Shorya, and Altay. It is separated from the Chinese platform (Tarim massif) by a thick belt of Tyan-Shan and Dzhungar-Alatau folds. Central Kazakhstan forms a considerable part of the Paleozoic geosynclinal region which is composed of numerous sectors all differing from one another in structure and development. The study of this area, due to its particular position, has a unique significance as a means of revealing the general processes governing the evolution of geosynclinal regions.

* * *

Until recently, two major views of the historical development of central Kazakhstan during the Paleozoic existed. One was formulated by an [early] investigator, N. G. Kassin; the other, by N. S. Shatsky.

Kassin, in a series of investigations [34-37] developed the idea that during the Paleozoic central Kazakhstan was subjected to pronounced structural alteration. Basing his theory on paleogeographic data and on the duration of the Caledonian stage, the author distinguished a series of zones characterized by varying degrees of tectonic activity within the territory. He described these zones as geosynclines, mobile shelves, platforms, and continental blocks. However, in adopting a terminology developed for western Europe by C. N. Bubnov, Kassin, as was later noted by Shatsky [102], arbitrarily changed the intrinsic meanings of these terms. Actually, Kassin's geosynclines are major synclinoria; the mobile shelves, limbs of the synclinoria; the platforms and continental blocks, either anticlinoria, groups of anticlinoria, or internal massifs. The structure of central Kazakhstan was thoroughly transformed at the beginning of the Variscan stage. In its eastern and southeastern parts, the strike of the folds and the location of the major troughs did not change to any great extent. In the western and northwestern parts, the orientation and location of the anticlinal and synclinal systems were completely altered; the strikes of the Hercynian folds intersect the strikes of the Caledonian at angles of 45° to 90°. The central point of Kassin's theory was the conclusion regarding the independence of Caledonian and Variscan stages of development and the retention of a geosynclinal regime throughout the Paleozoic. He also extended this conclusion to include magmatic and metallogenic development.

Kassin's views were critically reviewed by Shatsky [102], who, at the same time, presented a new theory on the tectonic structure of central Kazakhstan. Shatsky showed that during the Paleozoic geosynclinal stage of development central Kazakhstan comprised a system of anticlinoria and synclinoria which were formed over a long period of time. The strikes of these complex fold structures are parallel to

¹Translated from Osnovnyye cherty paleozoyskoy struktury tsentralnogo Kazakhstana: Moskovskogo Obshchestva Ispytateley Prirody, Byulleten, Otd. Geol., 1959, no. 1, p. 3-38.

the Ural system in the west and to the Tyan-Shan system in the east. In the deeper anticlinorial zones, major undulations which outcrop in the west and the northwest have formed. According to Shatsky, a successive development is characteristic for the Paleozoic structures of central Kazakhstan. He does not admit the alteration of central Kazakhstan structure during Variscan folding and, consequently, the "intersection" of the fold strikes. This investigator attributed the discordance in the strikes of the older and younger folds either to the formation of superimposed depressions (this concept was first introduced into literature by Shatsky in an article on Kazakhstan) or to azimuthal unconformities, often forming in deep folded areas.

Thus, Shatsky has developed a completely new theory on the structure and development of the central Kazakhstan massif. At the basis of his proposed scheme is the principle of inheritance in the development of fold structures. Moreover, he thought that central Kazakhstan is characterized throughout by a geosynclinal regime of development. He employed this concept in the tectonic map of the U. S. S. R., at a scale of 1:4, 000, 000 [104].

The ideas of Kassin and Shatsky for a long time opposed one another as separate thesis and antithesis. Meanwhile, new ideas on the geologic history of central Kazakhstan have appeared.

A. D. Arkhangel'sky [4] focused attention on the differences in development of the western and eastern parts of central Kazakhstan. Using the data of Ye. D. Shlygin [107] and many other investigators as a basis, Arkhangel'sky proposed that an intermediate massif was formed in west-central Kazakhstan at the end of the Caledonian stage; this massif was to have been a separate nucleus for the consolidation of the Ural and Tyan-Shan Paleozoic geosynclines. This massif divided the geosynclinal area into two secondary geosynclinal belts in the Variscan stage: the Ural belt and the eastern Kazakhstan belt. This idea was supported and further developed in a series of works by various investigators. D. G. Sapozhnikov [87], Shlygin [108], and P. N. Kropotkin [45] were some of the first to come to the conclusion that the western part of central Kazakhstan is related to regions of Caledonian folding, in which the geosynclinal stage of their development had been completed in the Devonian. A similar thesis was developed by V. V. Beloussov in his General Geotectonics [7].

Several years ago, as a result of numerous geologic investigations in cooperation with personnel of the Moscow University and the Moscow Geological Research Institute, the author thoroughly reviewed [13] his previous views on the tectonics of central Kazakhstan and undertook

to examine the structure and history of its western (Caledonian) part with the assumption that the western and eastern fold regions of central Kazakhstan were of different age. This investigation was further developed in the works of O. A. Mazarovich [49], A. Ye. Mikhaylov [57, 58], V. G. Tikhomirov [97], and Yu. A. Zaytsev [30]. This work has also been reflected in the tectonic map of the U. S. S. R. at a scale of 1:5, 000, 000, as well as in the text of the appended explanatory notes [96].

Very similar views have lately prevailed among geologists studying the Tyan-Shan. A paper published recently by N. M. and V. M. Sinitsyn [93] is typical in this respect; the paper presents a structural scheme and a description of Paleozoic development of this mountainous region. Reviewing the ideas of D. V. Nalivkin [62, 63], V. A. Nikolayev [68], A. V. Peyve [70], and other investigators regarding the Caledonian age of the central Tyan-Shan, the Sinitsyns distinguished within the northern area an ancient zone of Caledonian folding which is bordered on both the northeast and south by regions of Variscan folding.

A third major view on the structure of the central Kazakhstan Paleozoic massif has been formed; in the opinion of the author, this third view is embraced by the largest group of geologists studying the structure of this region. The author will not attempt to give the usual systematic description of the geology of central Kazakhstan. This is scarcely necessary, for major works are at present being completed on the evaluation of geologic studies in central Kazakhstan, accumulated over the last few years. More important, in our opinion, is the examination of general principles governing the structure and historical development of the central Kazakhstan massif in the Paleozoic. The formulation of a methodologically and factually accurate tectonic hypothesis is much more significant in the solution of practical problems of the processes governing the distribution of valuable mineral deposits. This hypothesis is now being developed by investigators working in various scientific institutions in our country. This hypothesis can hardly be considered fully formulated or substantiated. Nevertheless, the first attempts to apply the new concepts to the Paleozoic structure of central Kazakhstan have given hopeful results.

MAIN FEATURES OF PRECAMBRIAN AND PALEOZOIC STRATIGRAPHY

Rocks of various age and origin comprise the geologic structure of central Kazakhstan. In several regions, Archean and Proterozoic metamorphic rocks outcrop for considerable distances. Metamorphosed massifs of migmatite frequently penetrate the sedimentary mantle. Riphean [Precambrian] rocks, typically accompanied by ophiolitic development, are widely

distributed throughout central Kazakhstan. Complex, commonly very thick folded Paleozoic rocks, cut by intrusions of various ages and composition, are also widespread.

The western regions of central Kazakhstan differ considerably from the eastern parts in their middle and upper Paleozoic sections, the thickness and composition of the beds deposited during this era, the development of volcanism, and the nature of tectonic activity. The western parts of central Kazakhstan are similar to areas of Caledonian-type folding; the eastern parts are more or less typical of Variscan regions.

Precambrian

Precambrian rocks are of greatest areal extent in the west in the Ulutau massif and in the northwest in the Kokchetav massif [99, 100]. Elsewhere, they outcrop in the nuclei of major anticlinoria (Yerementau Mountains [19], Chingiz Range, south and north of the Golodnoy steppe [23, 53, 72, and others], and several localities in the Sarysu-Teniz watershed [13]. The lower strata, possibly Archean, are composed of various gneisses, eclogites, mica schists, amphibolites, and rare carbonates. They are 7 to 9 km thick and frequently intruded by granite-gneiss and gabbro-amphibolite. The younger Proterozoic series consists of a great thickness of metamorphic, igneous, and sedimentary rock (12 to 15 km). The large lower part of the section is composed of green schists of varying composition: porphyroids, porphyritoids, granitic-quartzitic, blastopsammitic, micaceous-quartzitic, and other types of schists and marble. In the lower part of the Ulutau section, iron quartzites are widespread (Karsakpaya jaspilite formation, recently described by M. S. Markov [51]). In the upper part of the section, in north-central Kazakhstan, the Golodnoy steppe, and the Balkhash area, thick layers of massive quartzite and phyllite are widely distributed. In various parts of Kazakhstan, the Proterozoic formations differ in many basic features, although they are invariably contained in characteristically geosynclinal structures.

The Urtyndzhal series occupies a unique position in the Precambrian section. Throughout the territory, this series is composed of characteristic multicolored jasper, jasper quartzite, metamorphosed basic and siliceous intrusives, and minor carbonate rocks. The Urtyndzhal series is locally intruded by ultrabasics (altered to serpentine), plagioclase granites, and gabbroids [98]. The age of the ultrabasites of central Kazakhstan, in the author's opinion, has been inadequately determined. Until recently, a majority of investigators have assigned these intrusions to the Ordovician [11, 37, 98, and others] based on the supposition that the enclosing rocks of these intrusions, the volcanic-jasper Urtyndzhal

series, was Ordovician. New data on the age of the Urtyndzhal series necessitated a revision of views on the age of the ultrabasites. R. A. Borukayev [18] was one of the first to propose a Precambrian age (upper Proterozoic) for these rocks. This point of view is now shared by many investigators. Without contradicting this opinion, the author does not exclude the possibility that they may be Cambrian, in the same way as this has been determined for single-type formations in the Gornyy Altay by V. A. Kuznetsov. Ultrabasic intrusions could have resulted from the final stages of Baikal folding.

The Urtyndzhal series differs from lower Proterozoic formations by a lesser degree of metamorphism and in petrographic composition. It is separated throughout from the metamorphosed Proterozoic complex by a regional unconformity. In the Boshchekul region, R. A. Borukayev [20] and his associates have determined that Lower Cambrian rocks, identified paleontologically, overlie rocks analogous to the Urtyndzhal series (the so-called Yerementau suite). The metamorphic structure and stratigraphic position of the Urtyndzhal series suggests that this series may be synchronous with the Riphean formations of the Urals and the Russian platform, the Sinian formations of China, and other similar formations [15, 72, 73, 105, and others]. The Urtyndzhal series is widely distributed throughout central Kazakhstan. It forms anticlinal nuclei in the anticlinoria of the Bayanaul region, Chingiz Range, Tekurmas, Balkhash, and Golognoy steppe. The series maintains constant composition, structure, and thickness (from 3 to 5 km) throughout the territory. Studies on the Urtyndzhal series indicate that during the long period of deposition and before the Paleozoic era, geosynclinal conditions of crustal development already existed in central Kazakhstan. The geosynclinal troughs were characterized by intensive deep-seated disruptions accompanied by underwater volcanism which resulted in formation of ophiolites.

Cambrian and Ordovician

During the Cambrian and Lower Ordovician, the whole of central Kazakhstan was again characterized by a geosynclinal regime. Studies on the lower Paleozoic rocks are at present still far from complete. Many basic questions on stratigraphy and the distribution of lower Paleozoic series remain unanswered. However, in the past few years, the structure of the lower Paleozoic section in various parts of Kazakhstan has been determined as a result of regional geologic surveys. A full series of Cambrian and Lower Ordovician sections have been made for the northern arc of Tyan-Shan, the Karatau Range, the western limb of the Ulutau zone, northeast Kazakhstan (Yerementau-Boshchekul region), and the Chingiz Range. Separate lower Paleozoic sections have been recently described for the Balkhash area, the Dzhalair-Nayman zone of the Golognoy steppe, several regions in the western

part of central Kazakhstan, and other places. Throughout, they are characterized by geosynclinal volcanic-sedimentary series.

In the west and southwest, the Cambrian rocks are predominantly terrigenous; locally, they contain vanadium and phosphate (Karatau, Ulutau [40, 50]). In the northeast and east, the lower parts of the section contain thick series of basic extrusives, which are widely distributed (Boshchekul [20, 56] and other series). In the west and southwest, the Lower Cambrian section is 1,500 to 2,000 m thick; in the east and northeast, it increases to 7,000 m. The section of Middle and Upper Cambrian rocks in the extreme southwest (southeastern Karatau) is much smaller. Here, terrigenous rocks several hundred meters thick predominate. Within this same zone, the Lower Ordovician section (carbonate beds) seems reduced. The total thickness of the Middle and Upper Cambrian and Lower Ordovician (Tamdin suite) is locally as much as 3,000 m thick (in various zones of Karatau). In the northeastern and eastern regions, the Middle and Upper Cambrian sections are more complete. The Middle Cambrian (Agyrek, Maydan, and Sasyksor suites of Borukayev [19, 20]) are composed of silicic and intermediate extrusives, sandstones, and argillaceous shales totalling 4,000 m. A large find of trilobites (*Erbia*, *Dinesus*, *Meneviella-Doriagnostus*, *Anomocare-Phoidagnostus*, and *Acrocophalites*) and other fossils indicate beyond doubt that the enclosing rocks are Middle Cambrian. Upper Cambrian and Lower Ordovician rocks (Tortukuduk series of Borukayev [19]) unconformably overlie older beds. They are composed of extrusive-sedimentary strata 700 to 1,500 m thick in northeast and 1,500 to 2,000 m thick in east Kazakhstan. They contain a varied fossil assemblage, including trilobites (*Olentella*, *Aphelaspis*, *Kujandaspis*, *Irvingella*, *Peltura*, *Lotagnostus*, *Euloma*, and others). In central Kazakhstan (Balkhash area, Karaganda, and other regions) paleontologically determined lower Paleozoic rocks are almost unknown, although their presence is more than likely. Isolated outcrops of volcanic-sedimentary rocks containing remnants of Upper Cambrian trilobites [14, 31] and thick widely developed beds of micaceous sandstones containing Ordovician graptolites (*Phyllograptus typus* Hall, *Didymograptus* sp.) have been found in the Sarysu-Teniz watershed and in the northern Golodnoy steppe. The thickness of these rocks reaches several hundred meters.

Recently, Peyve and V. M. Sinitsyn [76] suggested that a platform regime of development prevailed in northern Tyan-Shan and central Kazakhstan during the Paleozoic. At this time, according to the authors, a gigantic platform existed in Eurasia, which was later (during Ordovician time) divided into several massifs (Tarin and others) separated by geosynclines. This notion is founded upon erroneous [early] concepts of lower Paleozoic stratigraphy in central Kazakhstan and northern Tyan-Shan.

As was later determined, within northeastern and eastern Kazakhstan, the entire lower Paleozoic section is typically geosynclinal (formation type, thickness, folding, metamorphism). In west and southwest central Kazakhstan and north of Tyan-Shan, the lower Paleozoic section is not completely developed; Middle and Upper Cambrian formations only occur locally. However, the decrease in thickness and absence of individual beds in the section is not a consequence of a platform regime, but is related to major tectonic movements during Baykal folding. As is well known, tectonic movements at this time also caused a reduction in the Middle and Upper Cambrian sections within the Russian and Siberian platforms. Some geologists have accepted the notions of Peyve and Sinitsyn in their studies of central Asia and Kazakhstan. They have partially influenced Borukayev, who, on the basis of their hypothesis, stated somewhat categorically: "The basic features of the tectonic structure in central Kazakhstan were the result of upper Proterozoic folding; final consolidation of the folded region occurred in the Cambrian. Further development of the region in the Paleozoic was of a different nature. The consolidated Proterozoic folds were deeply faulted and broken into blocks during the Caledonian tectogenetic phase; this resulted in the formation of new structure quite different from the Proterozoic structures in their development, form, and type." [18, p. 46]. One of the authors of this hypothesis (V. M. Sinitsyn), judging from the work which he performed in collaboration with N. M. Sinitsyn [93], has completely rejected his former views on the subject. Unfortunately, his hypothesis continues to influence the development of theories of individual scientists.

In the Middle and Upper Ordovician, central Kazakhstan was divided into two parts: the eastern and western zones (fig. 1). In the western part (margins of the Kokchetav and Ulutau massifs), a thick series of terrigenous flysch-like sediments containing individual beds of intermediate lavas was deposited [101]. The graptolites in these rocks (*Glyptograptus teretiusculus* His., *Diplograptus multidentatus* E. et W., *Pseudoclimacograptus scharenbergi* Lapw., *Rectograptus* cf. *pauperatus* E. et W.) indicate Middle and Upper Ordovician age. This series is 6,000 m thick. It persists throughout an extensive area along the western frontiers of central Kazakhstan from the Kokchetav massif in the north to Karatau in the south.

Thick series of poorly differentiated sediments were deposited in the major troughs of north and northeast central Kazakhstan during this epoch. They are distinguished by a considerably greater amount of volcanics (porphyrites and tuffs) and strata of organogenic limestones. Recently, a similar section has been determined within the Chingiz Range by Borukayev and N. K. Ivshin [21, 22] and I. F. Nikitin [67]. Thus, geosynclinal conditions continued

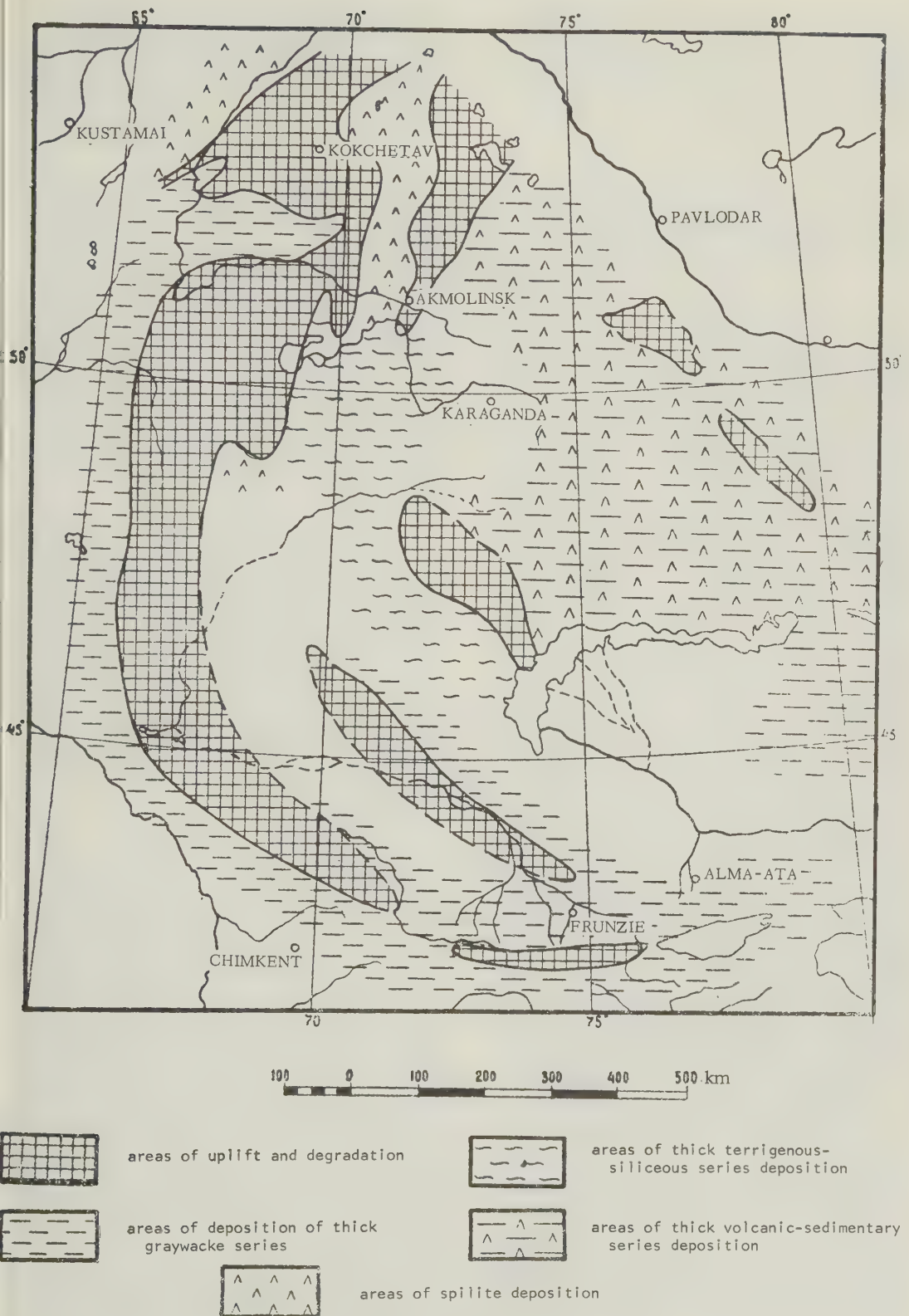


FIGURE 1. Middle and Upper Ordovician

during this epoch throughout all Kazakhstan. However, the appearance of terrigenous flysch-like series in the north is interesting in the respect that a well-known phenomenon occurred: the creation of conditions favorable for flysch deposition during the final stages of geosynclinal development [5].

At the end of the Ordovician, intensive tectonic movements occurred in the northwestern parts of central Kazakhstan; these were accompanied by thick granodiorite intrusions, the so-called Krykkuduk complex.

Gotlandian

Gotlandian (Original Ed.: The author prefers to use the old name "Gotlandian" for rocks which, according to the resolution of the Domestic Stratigraphic Committee of the U. S. S. R., should be called "Silurian.") sediments are widely distributed throughout central Kazakhstan. They differ sharply from lower Paleozoic series both in composition and thickness, and particularly in areal distribution. Gotlandian rocks are almost completely absent in northern Tyan-Shan; they are unknown in the Karatau. They are practically absent in the extreme west (Uluatau) and in northwest and north central Kazakhstan (fig. 2). In the literature the red sandstone facies of these regions are said to be Gotlandian. However, a detailed study of these facies in Uluatau revealed them to be Devonian [111]. The right bank of the Ishin river, north of the Dalnensky granite massif, is the only place where red molasse of Gotlandian age occur. Rocks of this age are widely distributed throughout the Balkhash area, in the Chingiz Range, in the Irtysh zone, and to the east, in the Karaganda region and Bayanaul zone within the Sarysu-Teniz watershed and in the northern Golodnoy steppe. Various formation types in the different structural zones are Gotlandian. In the northern Karaganda region and in the Bayanaul zone they consist of complex multicolored strata (N. A. Sevryugin [8].) The lower part of the section is composed of sandstones containing Llandoveryan and Wenlockian fauna (950 to 1,300 m); the upper part, reddish-brown porphyrites, albitophyres, porphyries, tuffs, sandstones, and conglomerates (approximately 2,000 m). This red-colored series forms a wide belt bordering non-Gotlandian rocks on the south and occupying a considerable area in northern Kazakhstan. It overlies lower Paleozoic rocks with sharp disconformity. It is covered unconformably by Devonian volcanics. To the south, within the Karaganda region and the northern Balkhash region, Gotlandian rocks comprise a series of greenish-gray graywacke sandstones and argillites interbedded with lenses and layers of organogenic limestones. According to M. A. Borisyak [16], N. P. Chetverikova [101], V. F. Bepalov [9], and others, the age of this series encompasses all of the Gotlandian; its thickness is between 4,000 and

5,000 m. In the Chingiz Range, Gotlandian rocks comprise a complicated multiple-facies complex, according to S. M. Bandaletov [6]. The complex is composed of thick graywackes, conglomerates, and various extrusives (porphyrites, albitophyres, and others). The total thickness of the section is estimated at 10,000 m, although this may be somewhat exaggerated.

Graywackes of the Balkhash area are bordered by a belt of shallow-water limestones and extrusives. According to B. M. Keller [38], who studied this complex in the western Balkhash area (Ak-kerme and other regions), coral reef facies as much as several hundred meters thick are found among the widely distributed limestones. The thickness of the extrusives is estimated at 1,500 m. The age of this complex is Llandoveryan to lower Ludlovian. The volcanic-carbonate strata of the western Balkhash area extend for considerable distances along the northeastern limb of the Bedpakdalin anticlinorium. Within the anticlinorium and directly southwest of it Gotlandian rocks are absent.

Thus, this volcanic-carbonate formation, as well as the red-colored volcanic complex of the Bayanaul region, occupied a marginal position around the geosynclinal troughs of central Kazakhstan during Gotlandian time. The areal distribution of sedimentation during this epoch is clearly reflected in the division of the central Kazakhstan Paleozoic massif into two parts: the western, characterized by incipient disturbances and an absence of any significant volcanic activity, and the eastern, characterized by intensive differential movements of great amplitude, general subsidence, and extensive volcanism.

Lower and Middle Devonian

During the Devonian, the structural differences between the western and eastern parts of this region became more strongly accentuated. In the west, in the Golodnoy steppe, the Uluatau massif, the Sarysu-Teniz watershed and its adjacent southern and northern regions, the Kokchetav massif, the Seleta and Olenta River basins, and the Bayanaul zone, a pronounced tectonic regime was established during Lower and Middle Devonian time. The tectonic disruptions were accompanied by volcanic ejections which formed a complex extrusive series. The first extrusions consisted of basic lava flows (diabase, porphyrites), and later ones, of lava and tuffaceous rocks of liparite-dacite composition. This series was deposited locally; it formed a wide, thick belt in the transition zone between the eastern (Variscan) and western (Caledonian) parts of central Kazakhstan (fig. 3).

The Lower and Middle Devonian extrusive series is widely distributed in the western Balk-

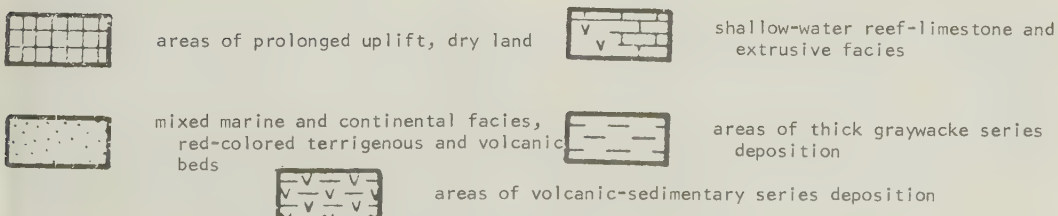
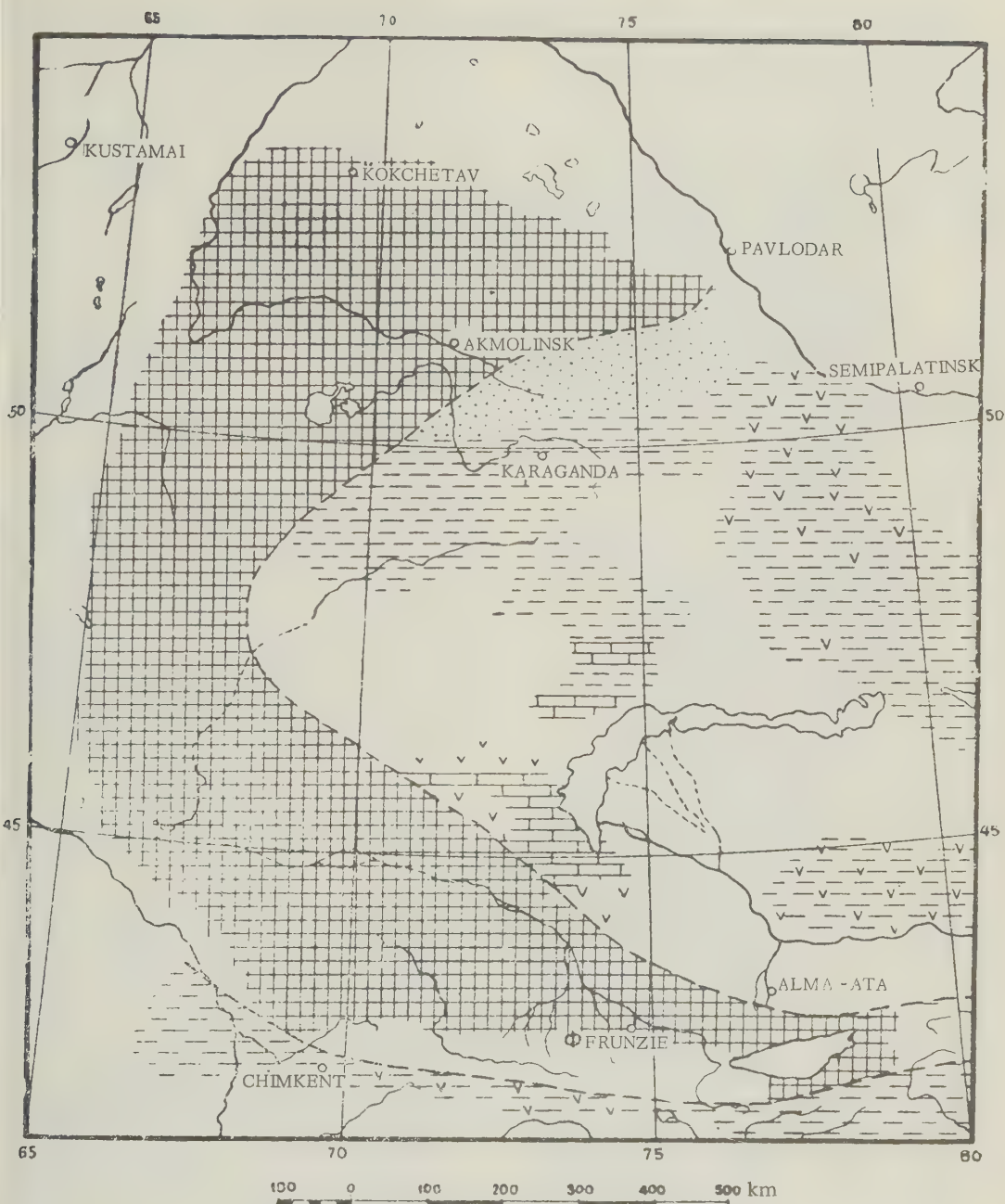


FIGURE 2. Gotlandian

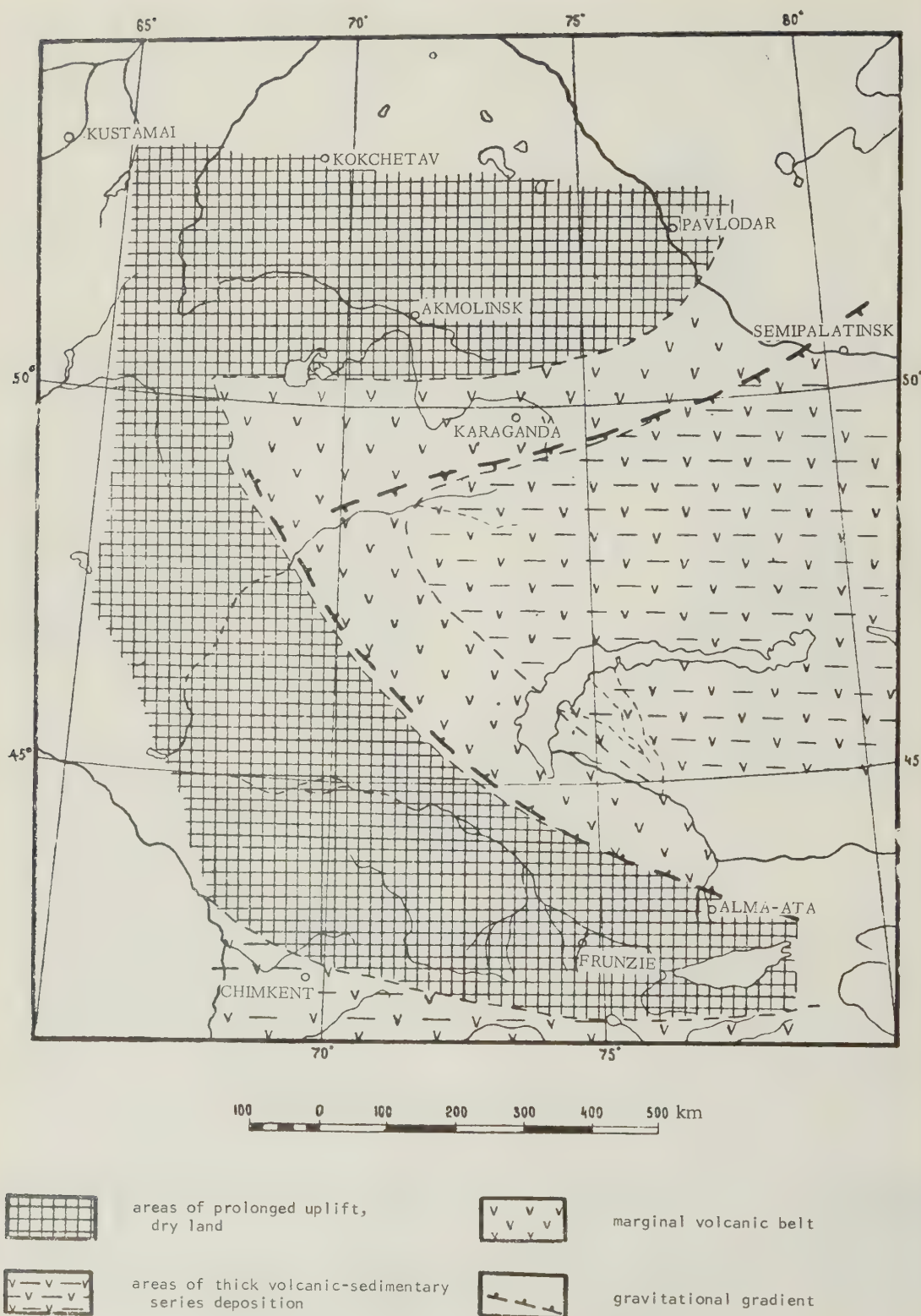


FIGURE 3. Lower Devonian and the lower part of Middle Devonian

hash synclinorium, as well as over large areas in the Sarysu-Teniz watershed. It is of considerable thickness (2, 500 to 4, 000 m). The series continues in a wide belt along the limbs of the Karaganda synclinorium; it is well developed in the Bayanaul zone. West of this marginal belt, the Devonian volcanics have a local distribution. Their development in certain localities is apparently due to individual-trough development; the trough are framed by large faults. Local depressions of this sort are the Ulatau Mountain region, the narrow marginal zone northwest of the Teniz depression, the Yakshi-Yangiztau Mountain region in the Kokchetav massif, the Korzhunkul marginal area, the Ekibastuz depression, and others. The deposition of Devonian volcanics throughout this area was accompanied by the formation of major intrusive granitoid massifs, at present occupying a considerable part of the territory [13, 94].

The intensive mountain building movements accompanying, and probably predetermining magmatic activity formed a high mountainous area during the second half of the Middle Devonian in west, northwest, and north central Kazakhstan. The uplifted structures were separated by deep and strongly downwarped intermontane depressions which were filled with coarse freshwater molasse. Such an environment lasted for a considerable length of time, close to the end of the Frasnian. This can be fairly well proven from age determinations on remains of plants and fish found in the molasse of several regions [90, 111]. The growth and simultaneous degradation of the mountain systems were accompanied by sporadic volcanic activity. In several regions, both in the lower and upper parts of the molasse, thin separate layers of basic, amygdaloidal porphyrite lava are found. As can be expected, the abundance of volcanic rocks in the section increases from northwest to southeast. The total thickness of the Middle and Upper Devonian molasse is from several hundred meters to 5, 000 m.

During this time (from the beginning of the Devonian to the end of the Frasnian), a geosynclinal regime was maintained in the eastern and southeastern parts of central Kazakhstan. In the northern Balkhash area, very complex volcanic-sedimentary beds formed; they were of mixed marine and continental origin. The lower parts of the section contained arenaceous-lutaceous rocks, basic and intermediate extrusives, and limestones containing brachiopods (Lower Devonian and early Middle Devonian). The thickness of this part of the section ranges from 1, 000 to 2, 000 m. Higher in the section are arenaceous-lutaceous beds containing large bodies of high-silica and basic lavas (which pinch out) and pyroclastics containing remains of Middle Devonian brachiopods and plants. Their thickness ranges from 800 to 1, 200 m. Finally, the upper part of the section, corresponding to the Frasnian, is composed of gray

and red sandstones, tuffaceous sandstones, argillites, and various extrusives; it contains remains of plants and, in the southeast, Mais bed brachiopods. The thickness of the upper section is 500 to 1, 000 m; the total thickness is 2, 300 to 4, 200 m [1, 3]. Still farther east in the eastern Balkhash area, the thickness of these rocks increases considerably, reaching 5, 000 m [83]. In the central parts of the major troughs, the importance of the dark sandstones and shales also increases.

The Famennian and lower Carboniferous of West Central Kazakhstan

During the Famennian stage, a marine basin formed in the western part of central Kazakhstan. It was characterized by a strongly dissected coastline and extensive shallow waters. Large flat areas of dry land occurred in the south where the contemporary Betpakdalin anticlinorium now exists [2]; large areas of land were distributed in the west and northwest regions. They included a great deal of the Turgay trough, all of the northwestern half of the Teniz depression and the Kokchetav massif, and undoubtedly extended north for a considerable distance to the western Siberian lowland. This land served as a barrier between the Ural and eastern Kazakhstan zoogeographic regions [62]. Famennian sediments, deposited over a wide area east and southeast of this land area, are characterized by a strong development of limestones and, in several places, dolomites. The terrigenous material plays an insignificant role. This undoubtedly indicates the level nature of the island relief; the Frasnian mountain systems were completely degraded in the Famennian stage. The thickness of the carbonate beds varies considerably from several dozen to 2, 000 m. Particularly notable thicknesses were observed in the Kingir trough which strikes southeast from the Ulatau massif [54]. Conditions favorable for chemical sedimentation developed in certain coastal zones: in the central part of the Teniz depression, drilling has revealed gypsum-bearing rocks underlying Carboniferous formations [39]; near the western limb of the Dzhezkazgan depression, individual diapir domes have been known for some time. The nuclei of these domes are composed of halogenic rocks of the Famennian stage [27].

During the Tournaisian, marine transgression continued. The sea encroached upon the margins of the Kokchetav massif, but an island environment was maintained. The sea was still separated from the Ural basin by an extensive land barrier which was situated in the region of the present Turgay trough. In the Visean, after maximum transgression (lower Visean), regression commenced; toward the beginning of the middle Carboniferous, the sea had receded from a large part of central Kazakhstan. During the Tournaisian and Visean, a

characteristic series of partly silicified limestones topped by red sandstones and argillites was deposited in west-central Kazakhstan. Their thickness in the deepest troughs is as much as 1,500 m [48].

At the beginning of the Namurian stage, terrigenous rocks began to predominate. Marine facies, intricately interbedded with continental, still persisted. In some localities in west and north central Kazakhstan, coal-bearing suites were being deposited during the lower Carboniferous. South and southwest of the Teniz depression, the deposition of coal-bearing strata occurred in the Namurian stage. In the southeast areas (Korzunkul, Ekibastuz, and other basins) coal formation probably began in the Viséan or, according to some investigators, in the upper Tournaisian. It should be noted that the disagreement among various investigators regarding the age of the central Kazakhstan Paleozoic coal-bearing suites is of such magnitude that it is impossible to draw any comparisons or correlations between the different studies. The thickness of the coal-bearing suite in the southern margin of Teniz is 500 to 1,000 m in the Ekibastuz-Bayanaul region, 550 to 1,350 m, and in the Karaganda basin, over 3,500 m.

Upper Paleozoic

The middle Carboniferous rests with sharp disconformity, and frequently with angular unconformity, upon lower Carboniferous and, locally, older rocks. In west-central Kazakhstan, the section begins with a thick, regionally distributed upper Paleozoic molasse. These complex continental formations are composed, in the lower part of the section, of alternating gray and red sandstones (usually crossbedded) and argillites; in the upper part, they are composed of terrigenous rocks and lacustrine limestones. On the basis of amphibian, reptilian, fish, ostracod, phyllopod, and plant fossil assemblages within the molasse, several middle and upper Carboniferous and Permian suites can be distinguished [48]. The total thickness of the upper Paleozoic molasse ranges from 2,000 to 4,000 m throughout the region. The unconformable position of this series, and the presence of rather coarse pebble conglomerates, clearly indicates the existence of intensive orogenic movements in the pre-middle Carboniferous. In determining the geologic environment in the western part of this region, it is important to note the lack of magmatic activity from the Famennian to the end of the Paleozoic. Later, at the beginning of the Jurassic or at the end of the Triassic, olivine basalts were extruded in several places in the Kokchetav massif and in the northern Turgay trough.

The formation of thick, fresh-water molasse which filled various intermontane depressions occurred not only in west central Kazakhstan, but also in the northern Tyan-Shan arcs. Popov

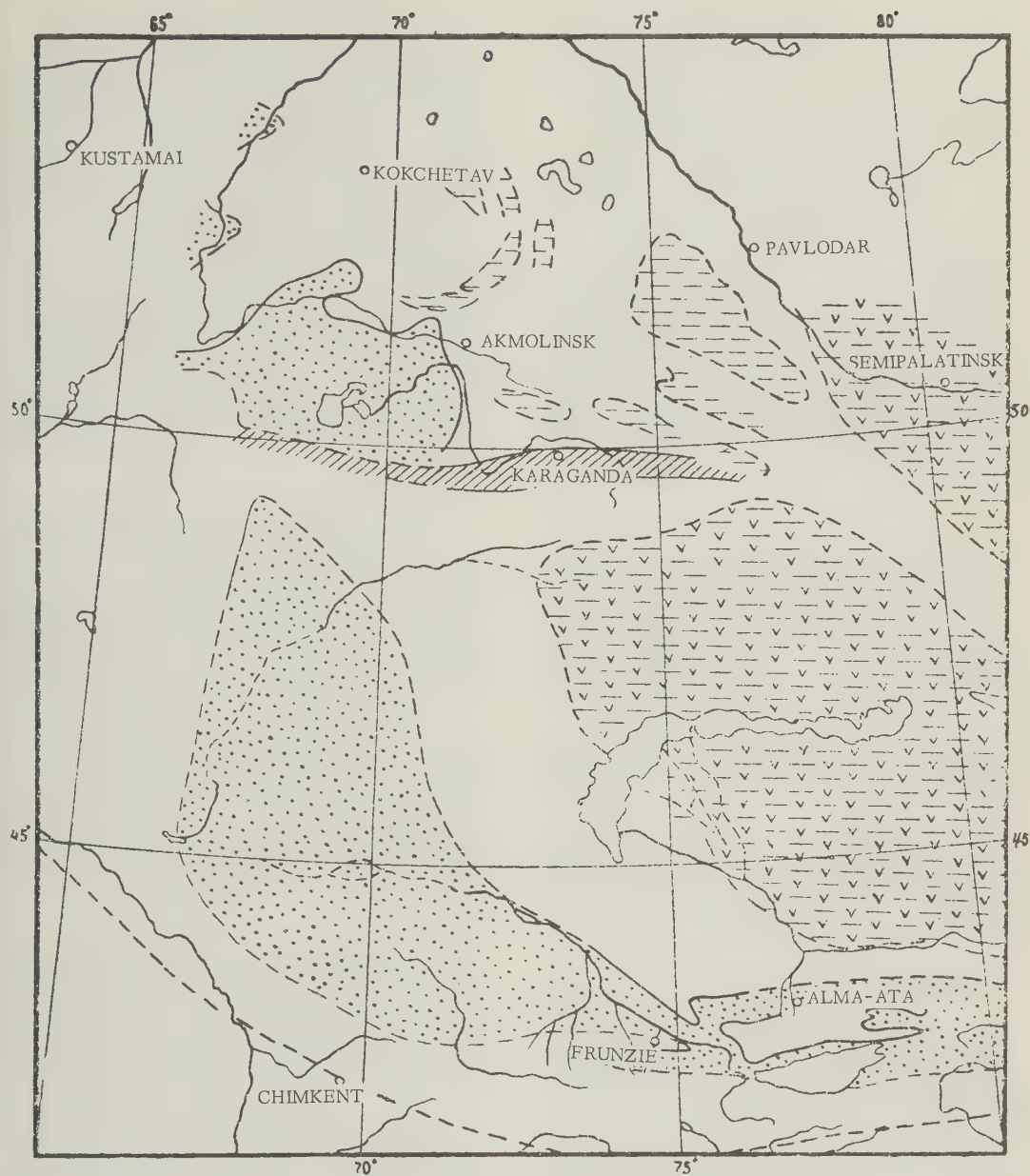
[79, 80] noted that the red upper Paleozoic formations are widespread from Kokchetav in the north to the Ketman range in the east. They occur in a gigantic arc embracing west central Kazakhstan, Muynukuma and northeastern Karatau, the depressions at the eastern ends of the Terska and Kunga Alatau, the Tekes depression, and the Ketmen range (fig. 4). Throughout this enormous area orogenic movements were intensively developed, thus facilitating the formation of the multicolored molasse.

Famennian stage, Carboniferous, and Permian of East and Southeast Central Kazakhstan

Somewhat different conditions existed during this period in east and southeast central Kazakhstan (from the Famennian stage to the end of the Paleozoic). Although the decline in the geosynclinal regime during the middle Paleozoic was noticeable in the west, it was not in the east. This is supported primarily by the structures within the respective rock complexes. In the northern Balkhash area (Shet and Aktogay region), according to G. I. Bedrov, P. P. Chuenko, and M. I. Aleksandrova [1] and N. A. Pypyshev [3], the Famennian and Tournaisian stages and the lower Viséan sections are composed of various sedimentary rocks: conglomerates, sandstones, marls, limestones, and others containing abundant and varied fauna. The thickness of these sediments is 1,050 m.

Sediments of the middle and upper Viséan, Namurian, middle and upper Carboniferous, and Permian are composed of a sedimentary-volcanic series 3,000 to 3,750 m thick. This is a very varied complex in composition and structure. Various porphyrites (pyroxene-plagioclase, amphibole-plagioclase, quartz-plagioclase, biotite-hornblende, and others) are widely developed and, to a lesser degree, quartz porphyry and various pyroclastic sediments. Agglomerates and tuff conglomerates are extensive. Terrigenous rocks are limited. In several beds, plant remains have been found; these facilitate the accurate dating of the enclosing rocks. To the east, within the northern Balkhash synclinorium, the section is not significantly different [8, 10, 95], but its thickness increases to between 6,000 and 7,000 m.

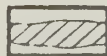
According to N. A. Savryugin [89], a very typical section occurs in eastern Kazakhstan within the Zayzan-Irtysh zone. Famennian sediments are absent over wide areas. Tournaisian rocks, frequently overlying the Devonian with sharp angular unconformity, are composed of a varied sedimentary-volcanic series. They include sandstones, conglomerates, siltstones, shales, albitophyres, quartz-porphyrates and their tuffs, as well as spilites, hornblende porphyrites, diabase, and other porphyrites. Beds of jasper, siliceous-argillaceous and carbonaceous shales, and limestones containing



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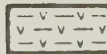
red-colored molasse



coal-bearing formation



"coal channel"



area of thick volcanic-sedimentary series deposition

FIGURE 4. Upper Paleozoic

marine fauna occur; the sediments are 2,000 to 2,650 m thick. Visean rocks form a very thick series of argillaceous, argillaceous-carbonaceous, and argillaceous-siliceous shales containing numerous layers of graywacke in the lower part of the section. The suite also contains spilites, porphyrites, tuffs, jasper, microquartzites, and quartzites. It is interesting to note that in the northwest Char belt, ultrabasites intrude this series. The total thickness of the Visean is 3,800 to 4,400 m. Upper Visean and Namurian rocks are in sharp unconformity with underlying formations. Their base is composed of a thick conglomerate. The suite contains various sandstones, argillaceous, argillaceous-siliceous, and other shales, and limestone lenses containing abundant fauna. Upper Visean-Namurian fauna occurs in the lower part of this suite; Namurian and early middle Carboniferous in the upper part. The thickness of this suite is 2,000 to 2,500.

Upper Paleozoic sediments within this region consist of thick layers of volcanic-sedimentary rocks. In the lower part of the section, various extrusives of high-silica and dacite composition predominate. The middle part of the section contains the Semeyatu extrusive complex; it represents a separate alkalic type (orthophyres, quartz orthophyres, anorthoclase and quartz porphyries). The upper part of the section contains a series of coal-bearing rocks and bituminous shales. These are of considerable thickness and areal extent in the Saur range (Kenderlyk).

Thus, the geosynclinal structures of east and southeast central Kazakhstan comprise a very thick section of Precambrian and Paleozoic rocks. The upper layers extend into the Permian and, locally, probably into the early Triassic.

Paleozoic Coal-Bearing Formations of Karaganda

The Karaganda coal-bearing basin occupied a distinct position in the general structure and facies scheme of central Kazakhstan near the end of the middle and at the beginning of the upper Paleozoic. The basin occupies a relatively small western section of an extensive synclorium which strikes eastward for more than 250 km. In the western extension of the Karaganda synclorium, south and southeast of the Teniz depression, a coal-bearing facies developed. These two structures form a continuous coal channel more than 550 km long [30, 77] (fig. 4). The Karaganda synclorium, as is well known, is filled with thick middle and upper Paleozoic beds. The Famennian and lower Tournaisian section is composed of thin carbonate beds (dozens of meters), typical of north and northwest Kazakhstan. Above this is a thick coal-bearing formation whose stratigraphic range is in dispute. A. M. Simorin [92], G. L. Kushev [46], V. K. Shchedvor [47], and quite a few other geologists suggest that the deposition

of the coal-bearing formation began at the end of the Tournaisian and was completed at the beginning of the middle Carboniferous. Kassins [37] has similar views. Petrenko [77] and some paleontologists and paleobotanists feel that the deposition of coal-bearing formations encompassed a considerably greater time interval. According to their data, the upper coal-bearing strata are upper Carboniferous or even Permian; the lower ones are Tournaisian and Visean. The lower beds are composed of argillites, marls, and sandstones 1,000 m thick. This part of the section contains beds enriched in phosphate [78]; in general character, according to Shatsky [106], it is very similar to the Kulm formation of central Europe. The coal-bearing series is composed of argillites, siltstones, sandstones, coal seams, and, in its lower part, limestones containing marine fauna. The total thickness is 3,250 to 3,400 m.

The whole section of the coal-bearing formation consists of gray-colored rocks, except for the upper beds (Shakhan suite) which consist of reddish-brown siltstones and argillites. The Karaganda synclorium has a characteristic absence of extrusives in the Upper Devonian and Carboniferous section. This is its principal difference from corresponding series in the Uspen zone and the northern Balkhash area to the south. In the last few years, Rengarten [82] has found ash tuffs both underneath and within the bottom parts of the coal-bearing series (Karaganda suite). However, it is quite evident that the deposition of this ash, which formed rather thin layers, is related to intrusive activity which occurred outside this synclorium in adjacent southern and southeastern regions (fig. 4).

Probably the most important feature of the section in the Karaganda synclorium is the presence of thick coal-bearing strata. However, this structure has several features in common with northwest and north central Kazakhstan. It contains thick, widely distributed volcanics of Lower and Middle Devonian age; for the most part, the Karaganda synclorium is situated in the Devonian belt of magmatic activity which separates the western and northern parts of central Kazakhstan from its eastern and southeastern parts within a clearly defined tectonic belt situated in the transition zone separating the Caledonian region of consolidation in central Kazakhstan and the Variscan geosynclinal area bordering it on the east and southeast. The Karaganda synclorium contains no evidence of magmatic activity in the Upper Devonian, Carboniferous, and Permian strata. Sections of the Frasnian and Famennian stages and the lower part of the Tournaisian stage are close in composition to analogous sections in the Bayanaul, Teniz, and other regions. These features sharply distinguish the Karaganda synclorium from geosynclinal regions situated to the south and east of it.

Variscan Intrusions

The briefly described difference in the structures of the eastern and western parts of central Kazakhstan are more fully understood after an analysis of the intrusive magmatic activity occurring at the end of the Devonian, Carboniferous, and Permian. Within east and southeast central Kazakhstan, no less than three major stages of magmatic granitoid intrusion can be distinguished during the Variscan. The first occurred at the end of the Devonian, possibly at the end of the the Frasnian. The second seems to coincide with major tectonic disruptions of the Namurian-early Bashkirian, which resulted in the unconformity that caused the superimposition of middle Carboniferous formations on older rocks. Finally, the third corresponds to the end of the Variscan folding which, according to A. G. Gokoyev [25, 26], could be extended to the Mesozoic.

The Upper Devonian massifs have many features in common with the leucocratic granite massifs of the Lower to Middle Devonian, particularly in structure and composition. They usually form large bodies, revealed by erosion, at relatively shallow depths. However, they have a relatively limited distribution and are concentrated within the inner part of the volcanic belt. Carboniferous and late Variscan granitoid intrusions are widely distributed in southeast and east central Kazakhstan. They form intrusions of considerable size; these penetrate middle and upper Paleozoic sedimentary structures. The late Variscan granitoids, according to Gokoyev [25] and V. S. Koptev-Dvornikov [41, 42], are characterized by a high-silica content (72 to 76 percent) and an alkalic content close to that of alaskite. They are almost completely devoid of assimilation and hybridization effects. Variscan granitoid intrusions are rare in west and northwest central Kazakhstan where geosynclinal development had been completed toward the end of the lower Paleozoic. They occur in the north and northeast. According to N. G. Sergiyev [91], the Koy-tac massif (Teniz-Korzhunkul region), the Bayanaul pluton [60], and several other structures are intrusive massifs of this age and type. The formation of Variscan granitoid intrusions within the northern and northeastern Caledonian zone of central Kazakhstan can be explained, probably, by partial regeneration during Variscan folding.

The basic differences in the structure of the middle and upper Paleozoic complexes of western and eastern central Kazakhstan reflect difference in their geologic development during the Variscan period of folding. At the beginning of the Mesozoic, these differences for the most part disappeared. In the early Triassic, all central Kazakhstan, and adjacent Tyan-Shan, Altay, and the western Siberian block were in the platform stage of development. The gigantic epi-Variscan platform, formed in the area occupied by the Paleozoic fold region, was charac-

terized by a relatively heterogeneous structure. The Paleozoic massif which was contained within the platform was, and continues to be, an extensive shield [103].

MAIN FEATURES OF PALEOZOIC TECTONIC STRUCTURE IN CENTRAL KAZAKHSTAN

Regional Tectonic Classification

Central Kazakhstan is characterized by a great variety of tectonic structures and by considerable differences in the general structural plan of its separate parts. Within central Kazakhstan, two main regions, differing in age, relationships of tectonic disruptions, and distribution of dislocation types, can be distinguished. These two regions fully coincide with the two above-mentioned regions of different Paleozoic section types.

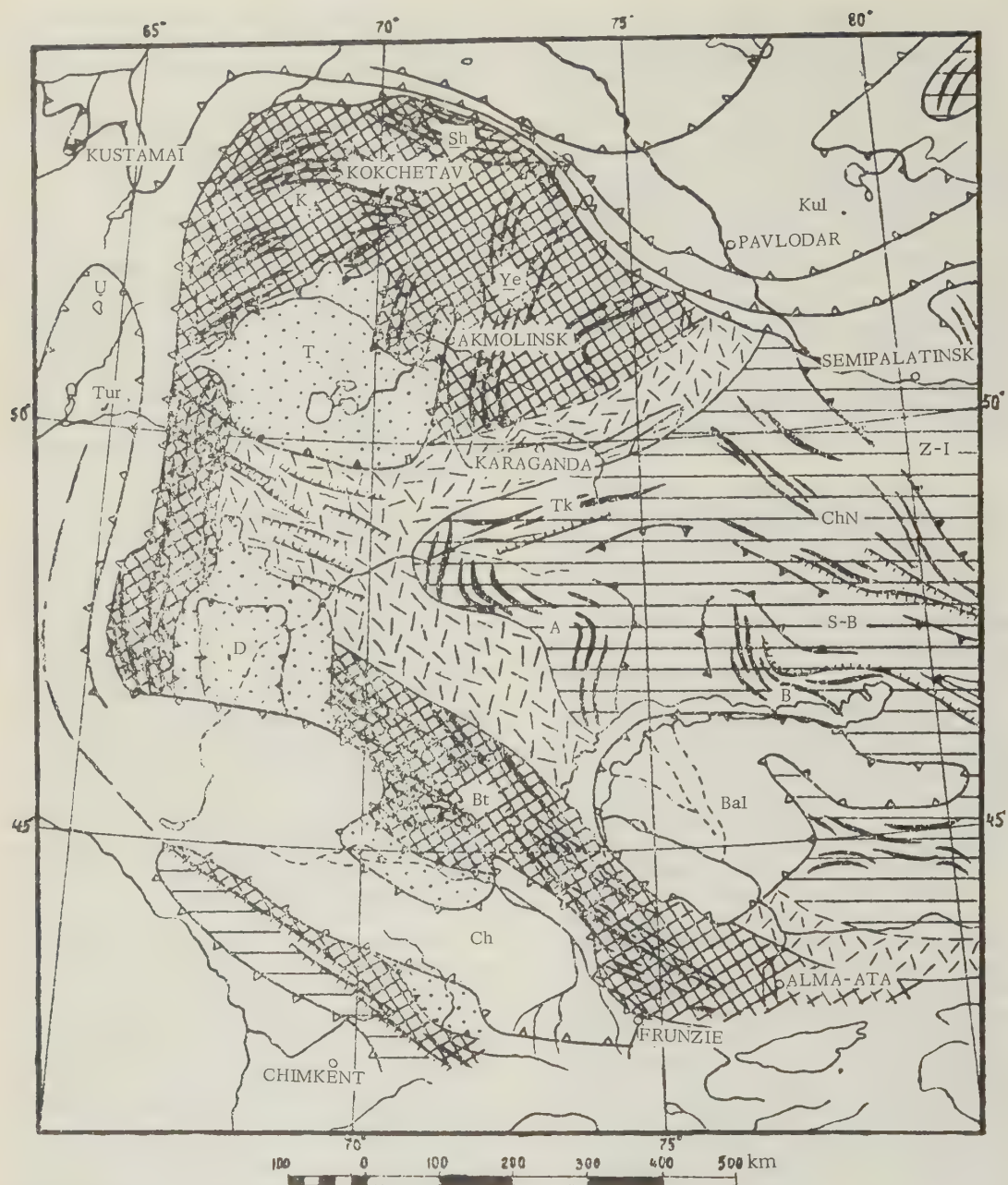
The first region, consisting of north, northwest, west, and southwest central Kazakhstan and the northern arcs of Tyan-Shan (fig. 5), is characterized by two sharply developed structures, the upper and the lower. It consists of a series of major anticlinoria and synclinoria; Precambrian and lower Paleozoic rocks form its lower structural stage. They are unconformably overlain by the upper structural stage composed of middle and upper Paleozoic rocks characterized by a scattered distribution, relatively small thicknesses, and occurrence of German-type block tectonic disruptions. The upper structural stage is composed of orogenic formations, among which molasse is widely distributed. This first region, as previously stated, has been lately more or less unanimously viewed as a Caledonian fold region.

The second region, encompassing the eastern and southeastern parts of central Kazakhstan (Irtys and Balkhash areas), Tarbagatay, and Dzhungar Alatau, is distinguished by a retention of structural unity at different depths in the Paleozoic section. It is characterized by a distribution of various types and sizes of linear folds composed of Paleozoic rocks grouped into systems of major anticlinoria and synclinoria. This region differs from the first by an evident development throughout the Paleozoic section of typical geosynclinal formations and a wide distribution of intrusive granitoid massifs formed during several intensive phases, the last of which occurred at the end of the Paleozoic.

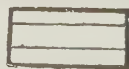
In the subsequent description, the author will, for the sake of brevity, refer to the first region as the Caledonian, and to the second as the Variscan.

The Caledonian Region

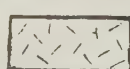
The Caledonian region encompasses extensive areas in north and northeast central Kaz-



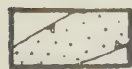
Caledonian



Variscan zone



marginal volcanic belt



Major depressions, superimposed on the Caledonian folded base and filled with upper Paleozoic molasse (T-Teniz, D-Dzhezkazgan)



Variscan synclinoria
Z-I - Zaysan-Irtysh
S-B - North-Balkhash



Major faults



anticlinoria (Caledonian:
Sh - Shatsky, K - Kokchetav,
Ye - Yerementau, U - Ulatau,
Bt - Bet-Pak-Dala, Kr - Karatau)
and Variscan anticlinoria
(ChN - Chingiz, Tk - Tekturmash,
A - Atasu-Mointin, B - Balkhash)



synclises and depressions of the epi-Variscan platform (Kul - kulunda, Tur - Turgay, Ch - Chuy, Bal - Balkhash)

FIGURE 5. Scheme for the Paleozoic structures of Central Kazakhstan

akhstan, situated north of the Karaganda synclinatorium, the Kokchetav massif, the Teniz depression, the Ulatau and Sarysu-Teniz uplifts, the Betpakdalin anticlinorium, the adjacent Dzheskasgan depression, Muyunkum, the Karatau massif and its extension, and the northern arcs of Tyan-Shan. The Caledonian region is separated from the Variscan on the east and southeast by the marginal Devonian volcanic belt (fig. 3). In the west, the folded lower Paleozoic and Precambrian rocks are covered by a mantle of friable Mesozoic and Cenozoic rocks of the Turgay trough and the Turan. Judging from data presented by V. I. Samodurov [86], they occupy a considerable part of eastern Turgay, bordered on the west by Variscan structures of the eastern Ural zone.

According to the Sinitsyns [93], the Caledonian zone pinches out in the southeast, within eastern Tyan-Shan, in a manner similar to that depicted in the scheme of the U. S. S. R. tectonic map on a scale of 1:5, 000, 000 [96]. To the north, in the southern part of the western Siberian platform, the Caledonian folded basement stretches for considerable distances, as has been observed from geophysical data [43, 81, and others].

The folded structures of Karatau and Betpakdala, located in the southwest, characteristically strike northwest, a typical trend for the northern branches of the Tyan-Shan. The ancient anticlinal and synclinal systems of the western regions of central Kazakhstan (Ulatau and Sarysu-Teniz watershed) strike south, like the Ural system. In the extreme northwest (Kokchetav massif, Maryev synclinatorium), the trend of the ancient folds is northeast and, locally, east. Farther east, a system of south-striking anticlinoria appears in the region of Yerementau and adjacent troughs. In the extreme northeast (Yekibastuz, Maykain, Bayanaul), a northeast strike predominates in the ancient fold structures. Thus, proceeding from south to north, all gradations from the "Tyan-Shan" orientation to the "Ural" orientation, and, from these, to the "north Kazakhstan" orientation are encountered. The northeastern (north Kazakhstan) orientation has a great significance in the general plan of the fold structures in the Ural-Sayan geosynclinal area. This orientation is characteristic of the Caledonian structures of western Tuva and Sayan. It is sharply developed in the Variscan folds of the Tom-Kolyvan zone. Apparently, this orientation is present in folds in several sectors of the western Siberian platform.

The degree to which the Caledonian structures of central Kazakhstan are revealed and accessible to observation varies considerably. In many places, the lower structural stage is concealed in middle or lower Paleozoic depressions which are filled with Devonian or younger sediments. However, the available data indicate

that certain structural features of the fold complex are maintained throughout wide areas. Some of the most important indications are: anticlinoria eroded considerably, as can be expected; highly metamorphosed Precambrian rocks outcropping in the nuclei; and limbs composed of the Urtyndzhal series and lower Paleozoic rocks. Each of these anticlinorial systems occupies a large area. They are 300 to 700 km along their strikes and 50 to 70 km wide.

The Karatau, Ulatau, Kirey, Kokchetav, Yerementau, and anticlinoria of other regions have similar structures (fig. 5). Rocks composing crests [of folds] have typical linear folding, and cleavage. They are frequently cut by steep, north-trending thrusts. In the crests of these ancient anticlinoria, Precambrian granite-gneiss intrusions occur. Locally, ultrabasites can be found. Frequently, they are penetrated by Devonian granite intrusions. The synclinatoria are usually filled with great thicknesses of Ordovician rocks. They are large proportionate synclinatoria [Tr.: *sopazmernyye* ?] and frequently heterogeneous troughs. Along their limbs, development of isoclinal folds and vertical attitude of strata can be frequently observed. In the central parts of the synclinatoria, simple fold forms predominate (angles of 25° to 50°); these are cut by longitudinal and diagonal folds.

The major Caledonian fold structures of the western part of central Kazakhstan are directly incorporated into a single system of arcs with the fold structure of northern Tyan-Shan. The Alatau anticlinoria in the extreme west and the adjacent Baykonur synclinatorium farther to the west and connected with the Kara-Tau are not only related by unity of structure but also in a striking similarity in the lower Paleozoic section and, apparently, in the Proterozoic section. The folds of the Kirey anticlinorium are closely related to the Betpakdala anticlinorial systems and, farther southeast, to the northern Tyan-Shan range in the same way. In this case, the persistence of the lower Paleozoic section, particularly the Ordovician, can also be noticed. The Caledonian fold structures of the northeastern part of central Kazakhstan (Yerementau anticlinoria and folds of the Ekibastuz-Maykain region) are extended to the southeast in fold structures of the Karaganda synclinal margins and, mainly in the Chingiz range system. In spite of the principal differences in the tectonic development of these zones during the middle and upper Paleozoic, they constitute a unity in the general orientation and structure of their lower Paleozoic series [20-22]. The main differences in their structure are due to the fact that the northern (Caledonian) anticlinal systems are deeply eroded and metamorphic Proterozoic strata outcrop along their axes; the southern (Variscan, as in the Chingiz) are at much greater depths and their axial parts are composed of lower, or even middle, Paleozoic rocks. Moreover, the synclinatoria, of the

northern zone are filled with thick Ordovician, and locally Gotlandian, sediments; in the southern zone, the major synclinal troughs contain very thick middle and upper Paleozoic rocks.

The upper structural stage, affecting middle and upper Paleozoic rocks, is frequently absent for considerable distances. This stage is separated from the lower structural stage by a major regional unconformity. If the lower structural stage is characterized by fully developed folding, the upper structural stage is characterized by tectonic movements which are related to vertical block faulting. Among these dislocations can be distinguished faulting systems of several orders. The major tectonic forms are uplifts and depressions.

The uplifts form extensive and relatively gently sloping domes, dozens to hundreds of kilometers in diameter. The amplitude of their vertical displacement is frequently very considerable (5 to 7 km). The uplifts form irregular, locally extended, and rarely isometric groups. In type, these are compound structures composed of ancient basement rock, subjected to erosion over the greater part of their area during the upper structural stage. Characteristic examples of this type are the Ulutau and Kokchetav uplifts of west-central Kazakhstan.

The depressions are wide and sloping troughs dozens and hundreds of kilometers in diameter. The dip of the strata along the limbs usually varies within 15° to 25° . The depth of the Caledonian fold base is locally 6 to 8 km in the depressions. Formation of the depression occurred during the upper structural stage. They are typical basins of contemporaneous deposition and subsidence [110]. The depressions, like the uplifts, are characterized by an isometric, irregular, and locally elongated configuration. Examples of this type are the Teniz and Dzhezkazgan depressions. The Teniz occupies an extensive area in west-central Kazakhstan; the Dzhezkazgan is located in the southwest, partly concealed under the Cenozoic mantle of the Chuy plain. In the southeastern extension of this plain, upper Paleozoic troughs of the northern Tyan-Shan arcs occur.

The uplifts and depressions are complicated by second-order tectonic disruptions. These consist of fold dislocations of various type and scale, horst anticlines and graben synclines, superimposed troughs of varying size, as well as domes, brachyantiforms, troughs, and brachysynclines.

Fold dislocations play an important part in the tectonics of the central Kazakhstan Caledonian zone. They obviously can be divided into a series of genetic types, distinguished both by size and importance in the general structure. According to Kazakh geologists, on the basic features of regional tectonics, the fold disloca-

tions have always played a significant role. In the early 1930's, V. P. Nekhoroshev [65, 66] in the Altai, and M. P. Rusakov, V. P. Vaganov, and I. S. Yagovkin [84, 85], in central Kazakhstan, began to distinguish complex and very extensive systems of disjunctive dislocations under the undefined designation, "fracture zones." At the same time, Shlygin [107] and D. I. Yakovlev [113, 114] presented then fashionable charriage hypothesis [Tr.: French theory concerning gigantic thrusts of great distances, first developed in the Alps]; in a series of central Kazakhstan regions, they distinguished major tectonic thrust sheets. Subsequent regional investigations have shown that the conclusions of the presence of charriage in central Kazakhstan are the result of misunderstanding. Toward the end of the 1930's, the fold structure of the central Kazakhstan Paleozoic massif was described with greater accuracy. The configuration of such large and clearly developed fold systems as the Chingiz anticlinorium, the Karaganda and Uspen synclinoria, and a series of other structures were outlined. Moreover, it became clear that "fracture zones" were not separate first-order tectonic disturbances determining the tectonic features of the region, but major and very important truncations of fold systems. For instance, theories on the uplift of the Uspen "fracture zone" and the formation of the Uspen synclinorium whose southern limb is truncated by this "fracture zone" were being expressed at the same time. Similar ideas have been recently applied to the "fracture zone" within the Rudnyy Altai [112].

In the past few years, Peyve [73-75] distinguished major tectonic features which he called "deep-seated faults," characterized by great linear extent and considerable penetration of the earth's crust. One of the basic features of these tectonic systems is their delineation of tectonic zones which are characterized by various degrees of development. Thus, in the Urals, according to Peyve [71] and N. A. Shtreys [109], the deep-seated faults frame the Tagil and Magnitogorsk zelenokamennyye [Tr.: a special type of metamorphic rocks] synclinoria which consist of specific middle Paleozoic complexes, including separate magmatic complexes, and unique tectonic structure. The faults separate these synclinoria from the geanticlinal systems of the Ulutau and Ural-Tobol anticlinoria. A similar role is played by "the main structural line of the Tyan-Shan," as distinguished by Nikolayev [69], which is better known as the "Nikolayev line," separating the Caledonian arc of northern Tyan-Shan from the Variscan structures of central and southern Tyan-Shan. Within central Kazakhstan, similar major persistent zones of deep-seated faulting also seem to exist. They are seen most sharply in the Caledonian zone and along its margins. Similar deep-seated fault zones were first distinguished by Peyve [73] in southern Betpakdala, where they form the very complicated Dzhalaïr-Nayman zone, described by Yakovlev [113, 114]. The northwest extension of this system into the Dzhezkazgan region and

within the Ulutau anticlinorium has been recently described by Yu. A. Zaytsev [30]. Apparently, a relatively large number of various deep-seated fault types exist. Recently, essentially all faults of great extent, of great penetration of the earth's crust, and of considerable duration within the tectonically active zone have been included in one group. Complex dislocations of the geosynclinal type have been referred to the deep-seated fault classification (zelenokamennyye zone of the Urals, the Dzhalair-Nayman zone of Kazakhstan), as well as the marginal faults framing the Precambrian platforms and gigantic archeogenetic [Tr. ?] crevasses occurring in ancient platforms (African and Rhine rifts, the Transbaikalia, and other structures); the dislocations were caused by various factors during various stages of crustal development. In this case, the term "deep-seated fault" fully corresponds to the "lineament" concept popular in western literature.

In this article, the author does not analyze the study of this relatively complex and still rather weakly developed problem, but considers it necessary to emphasize the principal differences among deep-seated faults of various types. Within the western, Caledonian part of central Kazakhstan, major folds, by their very nature related to tectonic disruptions of the geosynclinal stage of development (Dzhalair-Nayman zone type), are clearly distinguished. These disruptions follow the strike of the older structures; they define characteristics peculiar to the structures of the Caledonian folded base of west-central Kazakhstan and, from this point of view, are quite significant. However, in the postgeosynclinal (postorogenic) stage of development, these faults did not play a significant role. This by no means indicates that these faults had fully disappeared by the end of the geosynclinal stage. Their former significance had considerably decreased. A completely different type of fault had been distinguished by Zaytsev [29] in the southern part of the Teniz depression. This is a major fault cutting perpendicularly across fold strikes in the Caledonian base and resulting in the appearance of deep fault-rimmed troughs which was frequently filled with Carboniferous coal-bearing formations and thick layers of upper Paleozoic molasse. However, they are actually dislocations of a unique type; they are situated along the direct extension of the fault system into the transitional zone between the Caledonian and Variscan zones of central Kazakhstan (see below). Judging from the time of their inception, they are assigned to the Variscan.

Separate dislocations in Sarysu-Teniz uplift are related to this system of faults, described by P. L. Merkulov and A. Ye. Repkina [55], Kropotkin [45], G. I. Nemkov [64], A. A. Bogdanov [13], Zaytsev [29], V. G. Tikhomirov [97], and others. The Sarysu-Teniz uplift divides two of the largest depressions in west-central

Kazakhstan: The Teniz and the Dzhzhkazgan. The uplift forms an east-striking extensive arch incorporated in the Ulutau massif in the west. Throughout the Sarysu-Teniz uplift, a system of normal and reverse faults are developed; they are characterized by well-expressed south-east-striking linear features (fig. 6). These faults are 50 to 100 km long. Their amplitude ranges from 1.5 to 4 km; locally, it may be as much as 6 km. The faults are developed both in the Caledonian structural stage and in the overlying Variscan mantle. Judging from their relation to the Caledonian fold structures, these faults are dislocations of a clearly superimposed type; they are most sharply expressed by "intersection of the Caledonian folds by the Hercynian," the significance of which has been emphasized by Kassin. These faults are developed without any regard for the orientation of the ancient folds; they cut the fold strikes at angles of 60° to 90° . They form a system of linearly extended horst anticlines and graben synclines. The Caledonian fold complex and the widely distributed rocks of middle Paleozoic age outcrop locally within the horst anticlines. The graben synclines are filled with Upper Devonian and lower Carboniferous sediments. The anticlinal and synclinal structures have many features in common. They are alike in the general pattern of areal location, strike, configuration, size, and relation to faults. They differ in the extent to which the most clearly developed structures are independent graben synclines. The Caledonian graben synclines [30, 64] diagonally intersecting the northern Ulutau uplift (Arganatin massif) are characteristic. In the southeastern Arganatin, these graben synclines form the block-fold system of the Sarysu-Teniz watershed; in the north is a clearly isolated graben. Within the margins of the graben synclines, complex "fault-adjacent" folds and [Tr. : gofirirovka ?] of strata were frequently developed; these are practically absent in the horst anticlines. The graben synclines attained great intensity; they were commonly developed in Famennian limestones in the lower part of the Carboniferous system. The graben synclines and horst anticlines are extremely well developed in the Sarysu-Teniz uplift which they define. This type of dislocation has not been observed outside the Sarysu-Teniz uplift, although it is not impossible that it may have been developed elsewhere (probably in the Bayanaul zone).

The graben synclines and horst anticlines are typical results of block faulting in their morphology and mechanism of formation. They are related to German-type folding developed during the orogenic stage within former geosynclinal areas.

The block-faulted structures were formed partly during Lower and Middle Devonian time (during the period of granite intrusion and of greatest volcanic activity). During the Upper

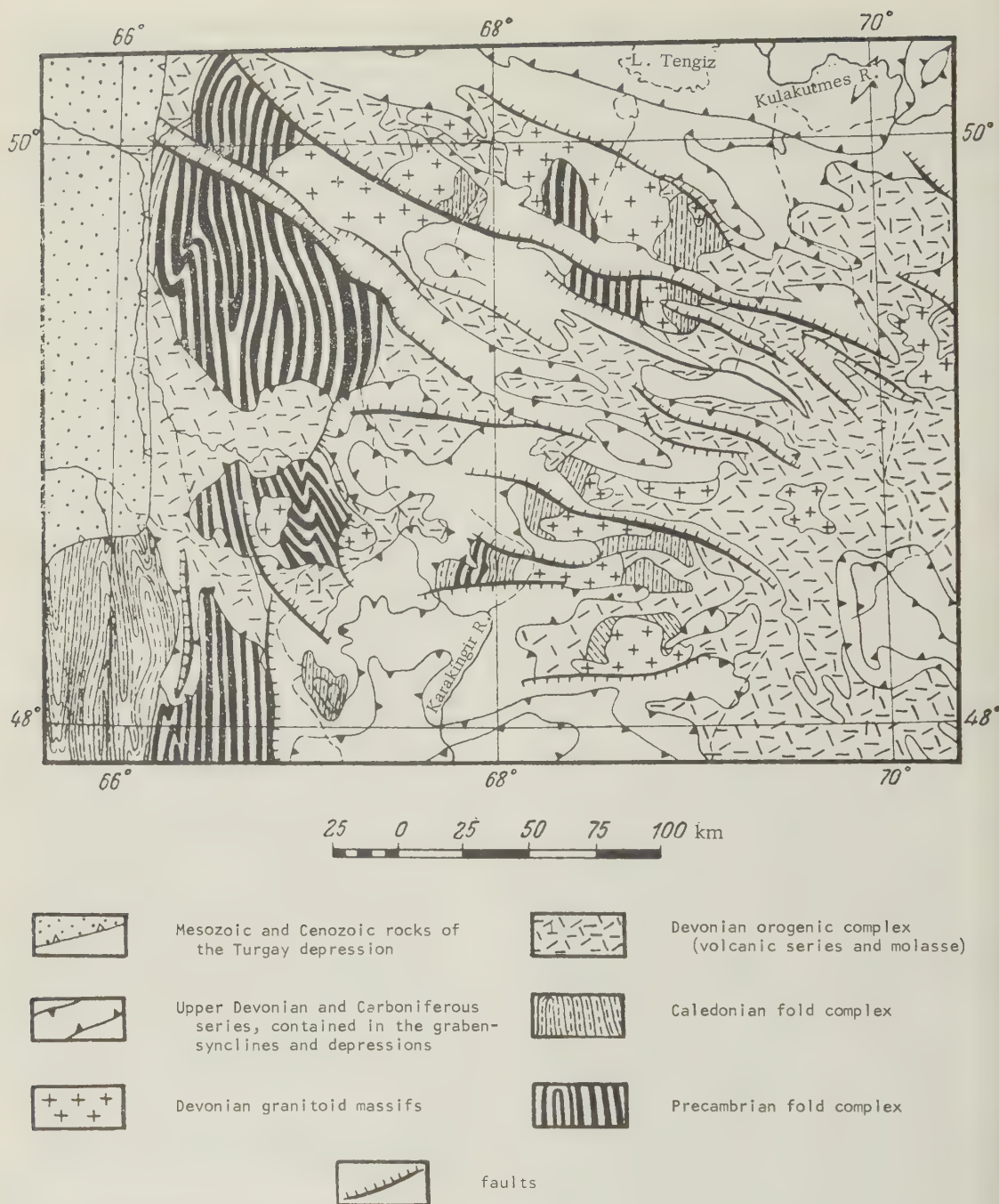


FIGURE 6. Tectonic scheme for the Sarysu-Teniz uplift

Devonian and the lower Carboniferous, subsidence occurred in some of the large graben synclines (Shubarkul and other structures), as can be seen from the great thicknesses of sediments contained within them [30, 54]. The final formation of these separate linear block structures is related to the final stages of Variscan folding.

Within the Caledonian region of central Kazakhstan, tectonic depressions, described by Shatsky [102] as "superimposed troughs," are widely developed. These have many characteristic structural features. The first and most important is their development in the locally distributed Variscan mantle. Devonian and Carboniferous rocks in the superimposed troughs overlie in sharp azimuthal unconformity the eroded surface of various structures of the Caledonian-folded Silurian, Ordovician, and Precambrian rocks. The depressions occur as rounded troughs, elongated brachyclines [brachyanticlines?], or narrow fault-adjacent synclines. The sizes of the tectonic depressions are varied; frequently widths are several dozen kilometers, but the area may be several dozens to thousands of square kilometers. Dips of the limbs of the superimposed troughs range from 10° to 90° . Normal faults are common borders and trough cross sections are normally asymmetrical. The "superimposed" nature of these tectonic depressions is based not only on the presence of the azimuthal unconformity but also on their formation of many diverse elements of the folded Caledonian base. The Teniz-Korzhunkul trough is superimposed on the northern Yereymentau anticlinorium; the Novo-Mikhaylov trough, controlled by a fault, is developed on the western slope of the Kokchetav massif; the trough within the Ekibastuz basin is superimposed on completely folded lower Paleozoic rocks; the Kuu-Cheku trough is developed upon an extensive monocline composed of middle Paleozoic rocks; the Sulu-Medine trough diagonally intersects the Nurin synclinorium composed of Silurian rocks.

The morphologic and genetic features of the superimposed troughs in central Kazakhstan have not yet been intensively studied. Very important observations have been made by N. A. Fogelman during his study of northern Kazakhstan. He was the first to determine the coincidence of all superimposed troughs with fault dislocations. The faults frequently pass through one or both trough limbs, may be covered by the rocks filling the trough, or may follow the strike of the trough, as can be seen in contemporary erosional surfaces. The superimposed troughs and the graben synclines may be considered quite closely related in origin.

The various domes, brachyanticlines, troughs, and brachysynclines of different size and form are second-order structures developed on the internal structure of the depression. Their distribution and form reflect features of

the lower structural stage [30, 55]. In several cases, they are controlled by the distribution of basement faults.

THE LOCATION AND NATURE OF THE TRANSITION ZONE BETWEEN THE CALEDONIAN AND VARISCAN ZONES OF CENTRAL KAZAKHSTAN

The Variscan zone consists of the Dzhungar Alatau, the Balkhash area, the Chingiz-Tarbagatai system, and the Irtysh-Zaysan zone. Farther east, the Rudnyy and Gornyy Altai systems are included. In the northeast, the Variscan folds are covered by the Mesozoic and Cenozoic mantle of the Kolundin depression, outcropping again in the Tom-Kolyvan zone.

The border between the Variscan and Caledonian regions of central Kazakhstan passes along the Karaganda and western Balkhash synclinoria which are primarily controlled by the features of the middle Paleozoic section (figs. 2-5). The problems of determining the borders of the Caledonian and Variscan regions of central Kazakhstan are very complex. During the compilation of the tectonic map of the U. S. S. R., at a scale of 1:5,000,000 [96], the problem of drawing the boundary was the subject of prolonged discussion. Finally, it was decided to consider the age of the granite intrusions as well as the nature and age of the tectonic and formation types. This treatment led to a series of errors. Part of the eastern border of the Caledonian nucleus was drawn along the Yereymentau anticlinorium on the basis of the presence in the northern part of this uplift of upper Paleozoic granitic intrusions (Koy-tas granitic massif). This border artificially divided a region of central Kazakhstan which, in its geologic structure and development, should be considered a unit; the Olenta river basin, Ekibastuz-Maykain, Bayanaul, and other regions were arbitrarily assigned to the Variscan fold region.

It is quite well known that the major Karaganda synclinorium separating the Caledonian zone of north-central Kazakhstan from the Variscan fold system of the northern Balkhash area is controlled by deep-seated tectonic faults. This is indicated by several factors. The Karaganda synclinorium is situated within the Devonian volcanic belt (the result of major faults through which magmatic melts flowed to the earth's surface). In the south, the Karaganda synclinorium marks a sudden anomaly in the gravitational field of the central Kazakhstan region [32, 59]. In the north, gravimetric anomalies are widespread; values equal Δg -20 to -50 milligals (mgl). The force of gravity to the south decreases to -120 mgl (the Buge region). Such a jump in the gravitational field, equivalent to a regional anomaly, undoubtedly reflects major qualitative changes in the structure of the earth's crust at very great depths. In the western extension of the Karaganda synclinorium, a separate narrow zone of deep depressions filled

with great thicknesses of Carboniferous rock (locally coal-bearing) occurs. From the conditions of its formation, this "coal channel" may be considered as a fault-adjacent trough.

It may be supposed that the second system of the anticlinal-type major tectonic faults extends southeast-northwest, from the southwestern margin of Lake Balkhash to central Sary-su, a river basin, and south along the northern Balkhash synclinorium. This system also coincides with the marginal Devonian volcanic belt, separating the Caledonian part of southwest-central Kazakhstan from the Variscan of the Balkhash area. It also clearly coincides with the position of the sharp gravitational anomaly (change in Δg over a short distance is 30 to 40 mg/l) [32], apparently caused by great differences in the subsurface structure of the tectonic zones dividing it. The western and northwestern extensions of these two systems of marginal faults are linear block dislocations in the Sarysu-Teniz uplift which, as in the southern Teniz "coal channel," are intensively developed in the Caledonian structures of west-central Kazakhstan and are superimposed perpendicular to the strike of Caledonian folds.

The marginal Devonian volcanic belt of central Kazakhstan and the marginal belt of Mesozoic folding in the Pacific Ocean zone have much in common [96, p. 71-72]. It represents a formation of the initial stage of geosynclinal trough development, sharply cutting across earlier structural elements (in this case, Caledonian); it also fixes the position of the major tectonic fault zones separating the area of geosynclinal development. Similarity of several structural features of these two volcanic belts reflects a similarity in many principal relationships existing between both the Caledonian and Variscan of central Kazakhstan and the Mesozoic and Cenozoic of northeast Asia.

VARISCAN REGION

The Variscan fold structures of central Kazakhstan form a system of geosynclinal troughs and geanticlinal uplifts. Geosynclinal troughs (or synclinoria) encompass extensive areas in southeast and east central Kazakhstan. In the Balkhash area, the structure of the northern Balkhash synclinorium, whose eastern part had been described by Rengarten [83] under the name of the Bakanass intrageosyncline, is very clearly developed. This is a very large (over 500 km long and 100 km wide) and complex fold-trough, filled with great thicknesses of middle and upper Paleozoic sedimentary-volcanic series and penetrated by upper Paleozoic granitoid intrusions. According to Rengarten, this synclinorium is bordered on the east by the southern Tarbagatau and northern Dzhungar deep-seated fault systems which control facies and thickness distribution within it. Rengarten's conclusions on the significance of deep-seated

faults in the structural and historical development of the northern Balkhash synclinorium cannot as yet be extended to the structure of other synclinorial regions. They possibly reflect the partial structural features of this tectonic zone.

The Irtysh-Zaysan geosynclinal trough differs in many respects from the northern Balkhash trough. The Irtysh-Zaysan trough is of considerable size and is filled with thick volcanic geosynclinal formations of middle and upper Paleozoic age. The trough itself is composed of several major fold structures: the Kalbin synclinorium, the Char anticlinorium, and other structures [61]. They are penetrated by Variscan granitoid intrusives and, what is particularly interesting, by hyperbasites.

Anticlinal structures in the Variscan regions have very varied structures. The Atasu-Mointin anticlinorium in the western part of this region has a deeply eroded crest composed of Proterozoic rocks [12, 23] and forms a separate S-shaped figure in plan. The Tekturmas layer of the anticlinorium, extending for considerable distances south of the Karaganda synclinorium, is composed of the extrusive-jasper Urtyndzhal series and penetrated by concordant intrusions of basic rock; it has a fan-shaped form in cross section. The Balkhash anticlinorium (It-Murun) is similar in structure to the Tekturmass anticlinorium.

The Chingiz-Tarbatagau geanticlinal system is much more complex in structure. This large fold structure is composed of several anticlinoria (Chingiz, Akbastau, Tarbagatau, and other structures) and synclinoria (Arbalin and others), described by N. G. Markova [52]. The anticlinoria are composed mainly of highly faulted lower Paleozoic rocks; the synclinoria of thick Gotlandian and Devonian rocks. Upper strata of the middle Paleozoic within this system have a limited distribution and small thickness. The decrease in thickness of the upper beds of the Devonian and lower Carboniferous, as well as in the predominance of sedimentary rock in their section (geosynclinal type) were the basis on which B. I. Borsuku [17] assigned the Chingiz system to the Caledonian fold zone of central Kazakhstan. One of the most outstanding features of the Chingiz-Tarbatagau geanticlinal system, clearly indicating its relationship to Variscan fold structures of central Kazakhstan, is the structural unity of all its stratigraphic subdivisions. Within the Chingiz, in the lower and middle Paleozoic sections, the number of relatively major unconformities is considerable. However, although reflecting the succeeding stages of the fold-system formations, they are not accompanied by major changes in the structural plan of this zone. This is the unique feature of the Chingiz structure which distinguishes it from any other Caledonian geanticlinal uplift of central Kazakhstan (Ulutau, Yerementau, or other structures). Other

differences are also seen in the Chingiz section were considerable thicknesses of Gotlandian and Lower Devonian sandy-shaly geosynclinal series are developed; they do not have anything in common with the decrease in rock thicknesses in the Caledonian zone. Within the Chingiz-Tarbagatai geanticlinal system, the "Caledonian unconformity," which divides the lower and upper structural stages of the Caledonian zone is not present. The existence of a great variety of types of tectonic disruption is quite characteristic for the Variscan fold system of central Kazakhstan. Accompanying various types of linear and arched fold structures are various normal and thrust faults which are widely distributed within the region. Their network in certain localities (Tokrau river basin) is so fine that the structure in some instances resembles a wire collander. On the whole, the tectonics of these systems can be described by the concept of "complete" folding.

CONCLUSIONS

The history of geologic development of central Kazakhstan is not yet fully known to us. Generally speaking, during the Paleozoic, it can be linked to the decline of the geosynclinal regime and its replacement by a platform-stage of earth-crust development.

The earlier periods of his history are known least of all. Judging from the development of thick volcanogenic-sedimentary series in all the described Precambrian sections of central Kazakhstan which have been intensely deformed, metamorphosed, and intruded, all investigators studying within this area agree that geosynclinal conditions existed in the Precambrian. In Riphean time, the geosynclinal regime had a special form favorable for the wide distribution of ophiolites and subsequent ultrabasic intrusions. The formation of major geanticlinal uplifts (Kokchetav, Yerementau, Ulutau, and

others) were related to the final stages of Baikal folding; these determined the basic features of main structural elements in central Kazakhstan.

The expansion of these geanticlines occurred during the lower Paleozoic. A major zone for Paleozoic areal consolidation having features of "a central massif" appeared in west, north, and southwest central Kazakhstan [4]. The formation of the zone took a relatively long time; the decline of the geosynclinal regime was lengthy (fig. 7). The Cambrian and Lower Ordovician geosynclinal troughs were still being filled with spilites and other rocks typical of geosynclinal structures. In the Middle and Upper Ordovician, these troughs were characteristic of miogeosynclines. They are characterized by the development of graywacke, and, locally, even flyschlike rocks. The expansion of the geanticline and retraction of the geosyncline was accompanied by a series of fold stages and intrusions. Granodiorites of the Kryk-Kuduk complex are of considerable importance.

Toward Gotlandian time, the relief of the region in the Paleozoic geosynclinal zone of consolidation was well defined. The final stages of Caledonian folding ended the geosynclinal regime within the Caledonian zone. Thus, due to the progressive expansion the formation of the Caledonian structures, encompassing a wide area in Tyan-Shan, occurred in central Kazakhstan.

Until recently, it was generally believed that Caledonian folding was limited in extent within the Paleozoic geosynclinal area. It was supposed that it encompassed only certain marginal sectors of the area (Sayan-Tuva, Ardenna, and Sudeta). Geosynclines were relatively narrow (Grampian). At the same time, it was supposed that the Caledonian and Variscan epochs represent different cycles of the geotectonic

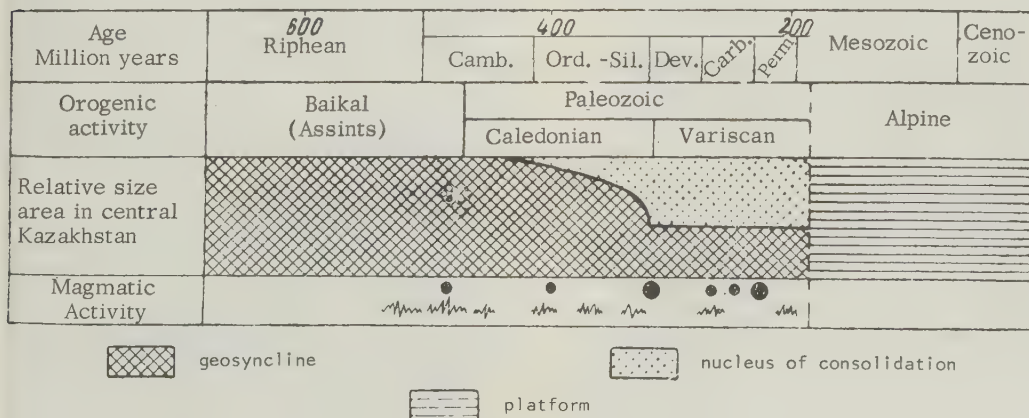


FIGURE 7. Scheme for the development of Paleozoic geosynclines in Central Kazakhstan

folding process in time and degree. The accumulated work on the structure and development of the Caledonian region indicates that the Caledonian epoch is an incomplete fold cycle; it differs in many respects from the Variscan [96, explanatory notes, p. 13]. The example of central Kazakhstan reflects admirably certain important features of structure and development in the Caledonian fold region. These features can be summarized as follows:

- 1) development by expansion of centers of consolidation;
- 2) reduction of the last stages of geosynclinal development, as seen in the almost complete absence of granitoid intrusions. Intrusions were concentrated in the last postgeosynclinal (orogenic) stage of development;
- 3) the decline of the Caledonian geosyncline was not followed by the direct formation of a platform. The geosynclinal regime was succeeded by an orogeny characterized by the developed of incipient porphyries and granites and, later, mountain-building movements, German-type dislocations, and molasse deposition; and
- 4) the orogenic regime within the Caledonian fold region was maintained throughout Variscan time until the closing of Paleozoic geosynclines and its conversion to the epi-Variscan platform.

A comparison of the structures and historical development of the central Kazakhstan Caledonian region and of the Caledonian structures of the southwestern margin of the Siberian platform indicates that the summarized features are common to both areas [30, 44]. The migration of fold development from the center to the periphery is very clearly expressed in these regions (the Caledonian of Siberia and from eastern Sayan to Altay). The upper (Variscan) structural stage is developed within them to a certain degree; it is composed of orogenic-type formations and separated from the Caledonian folded based by regional unconformity. The age of this unconformity is Lower Devonian throughout. During the first half of the Devonian, granitoids were intruded in both regions. German-type folding was similarly developed in both regions during the Variscan.

The Variscan folds of central Kazakhstan were also subjected to Caledonian tectonic activity which, however, did not result in the termination of the geosynclinal regime. Throughout Riphean time, in the beginning of the lower Paleozoic, all central Kazakhstan, apparently, was characterized by a unity of structure and development. It was during this epoch that the major geanticlinal uplifts and geosynclinal, troughs were formed; although subjected to Caledonian folding, they were not altered in basic structural plan and the geosynclinal development was continued throughout the middle and upper Paleozoic. The Variscan tectonic movements and magmatic activity in the Balkhash area and the Irtysh-Zaysan zone were terminated at the very end of the Paleozoic or even Lower Triassic with the closing of the

last Paleozoic Urals-Sayan geosynclinal area.

The Variscan tectonic movements were basically different in various regions of central Kazakhstan. They are represented by the development of linear (complete) folding in the Balkhash area and the Irtysh-Zaysan zone. Within the Caledonian nucleus of north, west, and southwest central Kazakhstan, various block-type dislocations resulted which are obviously typical of orogenic zones. However, despite this type of dislocation, in some sectors of the Caledonian area, the Variscan movements were reflected in various forms of geosynclinal-regime regeneration. Probably these phenomena were also partially manifested in northern Tianshan and the Bayanaul region of northern Kazakhstan by the intrusion of Variscan granite massifs.

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THE SAMOKOVSKA VALLEY¹

by

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ABSTRACT

Bulgaria's largest dam, "Stalin" is located in the Samokovska Valley. The average altitude of the valley is 950 meters, its area 185 square kilometers. The area is generally one of graben development modified by extensive erosion of surrounding mountains and Pliocene through Quaternary deposition of alluvium. Extensive erosion control measures will be required to prevent early silting up of the reservoir behind Stalin Dam. --M. Russell.

Since our [Bulgaria's] largest dam, the "Stalin" was built and an extensive survey related to the enlarging of its water catchment reservoir was carried out, the Samokovska Valley began more and more to attract the attention of the silviculturists and erosion experts as well as geomorphologists and geographers.

The survey recently undertaken by the engineering geologists for the eventual construction of a new dam, increased still more the interest in that valley from a tectonic as well as geomorphologic point of view. Drilling results permitted some conclusions about the differential aspects of the young tectonic movements observed in the periphery as well as inside the western section of the Samokovska Valley. The survey carried out in the northeastern part of the Samokovska Valley, in connection with the construction of the "Stalin" dam as well as most of the prospects carried out in the western part of this valley, as a result of man's activity aiming at changing nature and the social relations in the process of production have made extremely rich the theoretical conclusions concerning the morphologic development of this particular morphologic unity. Furthermore, the complete theoretical explanation of the genesis and the development of the Samokovska Valley created the prerequisite for planning a number of practical measures aiming at maintaining the efficiency of the "Stalin" dam as well as at determining the location, the nature, and the scale of future socialist constructions.

The average altitude of the Samokovska

Valley is 950 meters above sea level. That is the reason that it may rightly be considered as



FIGURE 1. In the Samokovska Valley

being the highest well-defined valley in our country. The valley has an area of only 185 square kilometers. The mountains that surround the Samokovska Valley are Vitosha, Plana Planina, Lozenska Planina, Vakarelska Planina, Septemvryiski Rid, Shipochanski Rid, Shumnatitsa Rid, Rila, and Belchinska Planina.

Most of the mountains bordering the Samokovska Valley rise slightly above its high plateau. Thus for example, if from the Samokovska Valley one looks at Plana Planina, Lozenska Planina, Vakarelska Planina, and Shipochanski Rid, one may see those mountains appearing as high flat plateaus, rising between 200 and 300 meters above the valley. At first sight it is difficult to convince the observer that they are true mountains because of their large flat plateaus deeply dislocated by erosion and gradually and imperceptibly sloping down to its periphery. But Rila and Belchinska Planina at the southern part of the Samokovska Valley are truly high mountains.

Because of its morpho-hydrography, the Samokovska Valley's area could be divided

¹ Translated from Samokovskata kotlovina: Geografiya, Nauchno-populyarno spisanie, v. 7, no. 7, p. 1-5, 1957, Sofia. JPRS Trans: L-558-N.

into two sections: the western section called Palakaryiska and the eastern one called Iskurska. The Palakaryiska section is characterized by having a clearly defined vast valley flat plain. The Palakaria River irrigates it, and that is why this section of the valley might rightly be called the plain of Palakaria. The Iskur River irrigates the eastern part of the Samokovska Valley. For its part this area may be divided into two plains: the plain of Gorno Samokovsko and the plain of Dolno Samokovsko. The heights of Prodanovski and Sredna Gora sloping down to the south represent in fact a clearly determined frontier between the plain of Palakaria and the plain of Gorno Samokovsko. The lake of Stalin dam has an area of 30 square kilometers and the lake's waters cover not only the plain of Dolno Samokovsko, but partly the plain of Gorno Samokovsko as well. The short Kalkovski canyon (breach-prolom) becomes a very beautiful strait (protok), in the crystal clear water of which are reflected the valley's slopes bordering the Iskur River. It is a pleasure on a calm day to ply with a motorboat the water of the dam lake, which extends over 12 kilometers in length and about 6 kilometers at its maximum width. Spontaneously one might think of the heroic workers, technicians and engineers who built the powerful concrete wall where the Cherveno-gradski breach (prolom) starts, and which retained the waters of Iskur - the second largest river in our country. Only three years ago, in the plain of Dolno Samokovsko, there were the villages of Shishmanovo, Gorni Passarel, and Kalkovo. Today, their former inhabitants and our entire people understand the economic value which the gigantic dam represents for our socialist Fatherland.

When one talks about the genesis and the morphologic development of the Samokovska Valley, one should point out that it is one of the valley's of the middle section of the Balkan Peninsula. By their origin and morphologic development all these valleys are related to the young tectonic movements in that part of the peninsula. These valleys represent tectonic depressions which form a belt connecting the Trakysko-Makedonski main group of mountains to the Srednogorski stretch (Ivitsa) of the young plicated (flexed) mountainous system. This thought is not only corroborated by the different recumbency of the folds of the surrounding mountains but also by the phenomenon of their spreading out of the andesite eruptions and the younger quartz-diorite and syenite intrusions. The mountains of Verila, Vitosha, Plana and the Lozenska Vakarelska and Septemvryiski Rid mountains are characterized by a predominating northern direction of the recumbency of the folds in

that section of the Samokovska valley, which borders the Sredna Gora mountain. One may observe just the opposite phenomenon in the Rila and Belchinska mountains. In the Rila mountain and particularly in the Belchinska mountain the southern recumbency of the folds is clearly visible.

The formation of the Samokov's valley came through a change of slopes which in the south determine the configuration of the old group of mountains located in the valley's section nearest Rila mountain. In the north, the change of slopes has carved up and shred the structure of the valley's section bordering the Sredna-Gora mountain.

The plain of Palakaria as well as the plains of Dolno and Gorno Samokovsko are grabens. The synclinal character of the slopes of these three separate sections of the Samokovska Valley does not appear clearly everywhere on the present land surface. As to the age of those three grabens, one might say that their formation did not take place at the same time and that they embody three different stages of the formation of the Samokovska Valley. The difference of ages of these three plains of the Samokovska Valley is corroborated by the synclinically conditioned mountainous slopes in their bordering sections as well as by the various sediments which might be found in the periphery of those plains. The abrupt slopes of the Verila and Belchinska mountains which here and there are faceted, may be found principally between the young step (levantine) of the Pliocene period and the flat surface of the plain of Palakaria. Furthermore, if one accepts the fact that Pliocene sediments found in the periphery of the plain of Palakaria are of the age of the Levant, there is no doubt that the ground depression observed in this section of the Samokovska Valley did not take place before the middle of the Levant period. That means that the formation of the plain of Gorno Samokovsko took place in middle Quater-



FIGURE 2. View from peripheral sections of the Samokovska Valley

nary. The fact that this plain is really a relatively young graben is also corroborated by the river glacier strata. The plain of Palakaria as well as the plain of Gorno Samokovsko came simultaneously into existence. But the plain of Dolno Samokovsko possesses some tectonic and morphological features which prove that the formation of the southwestern section preceded the northwestern one. Thus for example, while in the southeastern section of the plain of Dolno Samokovsko the synclinically conditioned slopes of Septemvryiski Rid are to be included between the young mountainous step and the flat surface of the plain, the faceted slopes in the northwestern section of the same plain are sloping down under the fourth terrace. In other words, the southeastern section of the plain of Dolno Samokovsko came into existence during the transitional period of the Pliocene to the Quaternary, and the northwestern section might be determined as not having come to existence before mid-Quaternary. The different age and the differential morphological formation of the valley of Samokov are quite typical features which deeply marked the present appearance of its land surface. The western section of Samokovska Valley, i. e., the plain of Palakaria, has all of the features which appear as most typical of the valley form and morphological complex. Besides the small terraces clearly appearing on the slopes of the Verila, Vitosha, and Plana mountains, which are remnants of an eroded and abraded surface, one may observe in the plain of Palakaria peripheral as well as internal valley-shaped depressions and elevations of the ground. Here one may justly say that the interior and peripheral swampland appears in that case as a proof of the existence of today's peripheral and internal valley-like group depressions. The opposite phenomenon, i. e., the young valley-like cuts in the Pliocene sedimentary surface, constitutes positive proof of the tectonic ground elevations in the periphery of

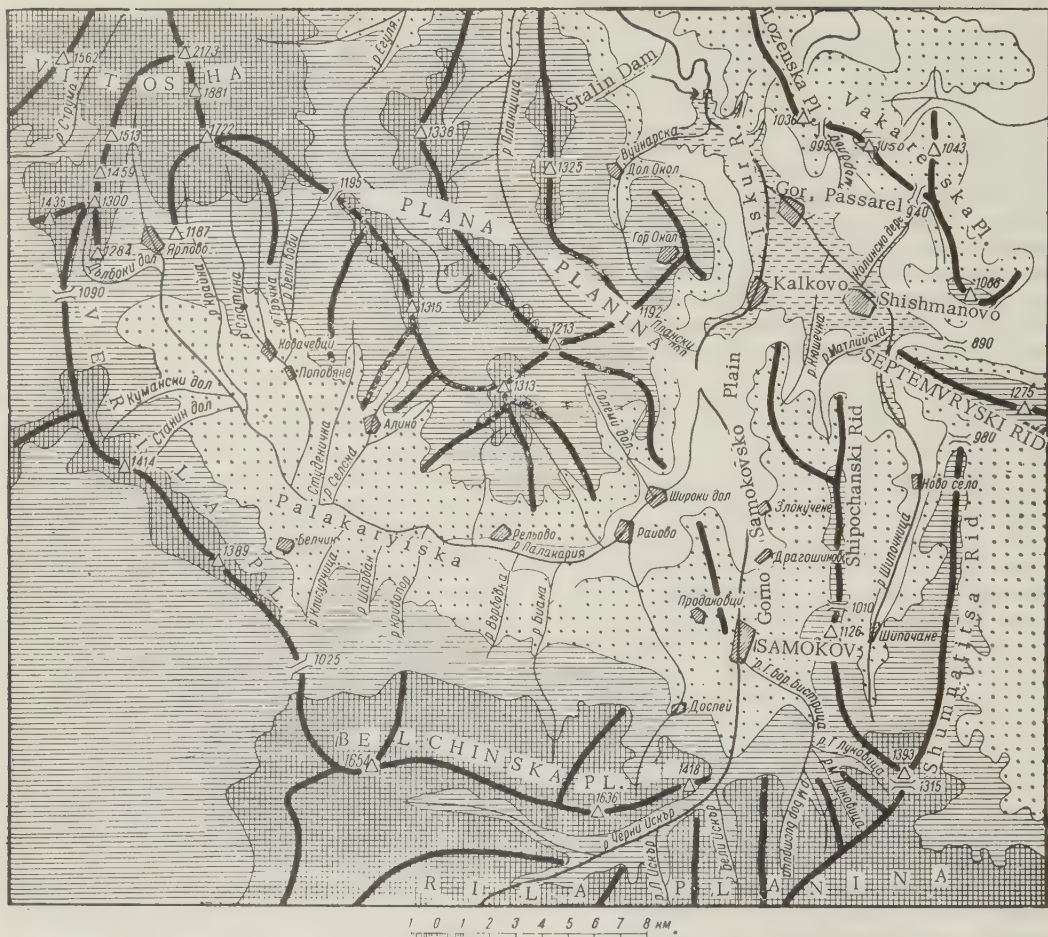
the valley. As to the isolated elevations of Rogovitsa and Grobina in the middle of the plain of Palakaria, they confirm the existence of the partial internal group elevations, clearly appearing in the background of the general depression of the valley-shaped flat surface. The above-mentioned morphological features of the plain of Palakaria do not apply to the plains of Gorno and Dolno Samokovsko. The typical peripheral and internal valley-like ground depressions practically do not exist in those plains and no internal partial ground elevations are noticed, except the elevations of Prodanovski and Sredna Gora.

In conclusion, in connection with the morphological aspect of the valley of Samokov one should say that in spite of having a tectonic origin, the final formation of the valley came about to a great extent through erosion. This contention is corroborated not only by the mountainous slopes bordering the valley but also by the clearly appearing terraces here and there on the slopes bordering the Iskur River. Here nevertheless one should point out, that the Samokovska Valley, being a section of the area connecting the Trakiysko-Makedonski main group of mountains to the Srednogorska mountainous chain (ivitisa) of the young plicated (flexed) mountainous system, has a typical asymmetric geomorphological profile. This profile is clearly emphasized by the vast alluvial cone of Iskur River which shows not only an intensified denudation in the section near the Rila mountain, but also a continuing accumulation of mud.

In today's socialist construction taking place in the valley of Samokov a central place is given to the gigantic "Stalin" dam, its utilization, and maintenance. The valley of Samokov has also some geomorphological features which are not favorable to the dam. One may stress among them the processes of erosion of the bordering mountainous slopes. Here the erosion appears in many forms: sheet wash, channeling, and gullyng. There is no doubt that controlling the erosion would diminish the accumulation of mud in the dam's reservoir and lengthen its life. The extensive survey permitted the planning of a number of measures which will restrict, to a considerable extent, the process of erosion and consequently the accumulation of mud. Particularly great attention is paid to soil erosion. The phenomenon of the horizontal erosion [sheet wash], observed in terrain having a declivity of more than eight degrees, is destroying not only the ground's structure but also creates the conditions for the development of vertical erosion. In the past, many of the



FIGURE 3. Ravines in peripheral sections of the Samokovska Valley



Morphological and hydrographic map of the Samokovska Valley and its bordering mountains.

Altitude Belts

- | | | |
|--|--|--|
|  a) below 900 meters |  - from 1000 to 1200 meters |  - pass |
|  b) the "Stalin" dam |  - above 1200 meters |  - drainage divides |
|  - between 900 and 1000 meters | | |

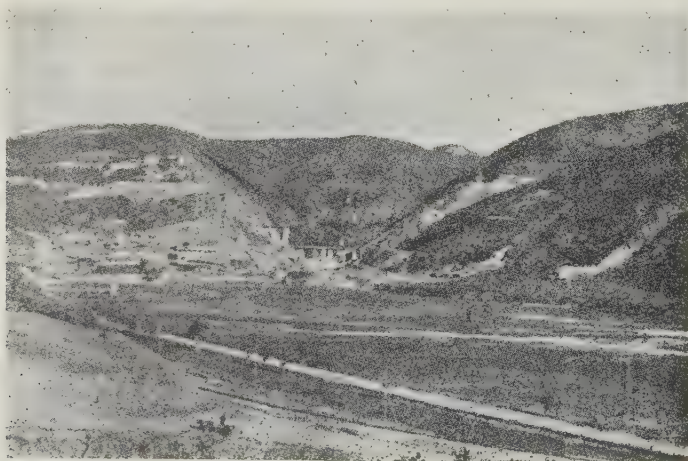


FIGURE 4. Stalin Dam at the start of construction

forest covering the slopes bordering the Samovkovska Valley were cut in order to meet the needs of mines for charcoal. By the destruction of the forest and plants there were created conditions for sheet wash, scour, and gullying all along the mountainous slopes bordering the valley of Samokov and particularly all along the slopes of Plana Planina. The agronomical, silvicultural, and technical measures carried out to date and those which will be carried out in the future constitute a positive guaranty for maintaining the economic efficiency of the "Stalin" dam. Nevertheless, it is necessary to pay greater attention to the erosion processes and means of controlling it in those sections which border the dam's reservoir. For this purpose it is necessary to make continuing morphological observations, which undoubtedly will make more successful



FIGURE 5. Stalin Dam

the struggle against the erosion and consequently against the accumulation of the mud in the reservoir of the dam.

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RUSSIAN AND EAST EUROPEAN GEOLOGIC ACCESSIONS OF THE LIBRARY OF CONGRESS

This section is devoted to a listing of selected geologic items appearing in the two publications of the Library of Congress: Monthly Index of Russian Acquisitions, and East European Acquisitions List. These lists are intended as a means of indicating to researchers in the earth sciences some of the material most recently available for screening, further review, and translation. For this reason the lists do not include material now, or soon to be, published in English. Emphasis is placed on Russian material; the extent to which items from East European sources are listed depends on the country and language involved.

A major function of the AGI translations program is the screening of foreign literature for material that should be made available to the English-speaking scientist. Researchers who need such material are urged to review these lists and send us their recommendations for consideration by the editors; the translation needs of all geologists will be served better thereby.

-- Managing Editor

MONTHLY INDEX OF RUSSIAN ACCESSIONS

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